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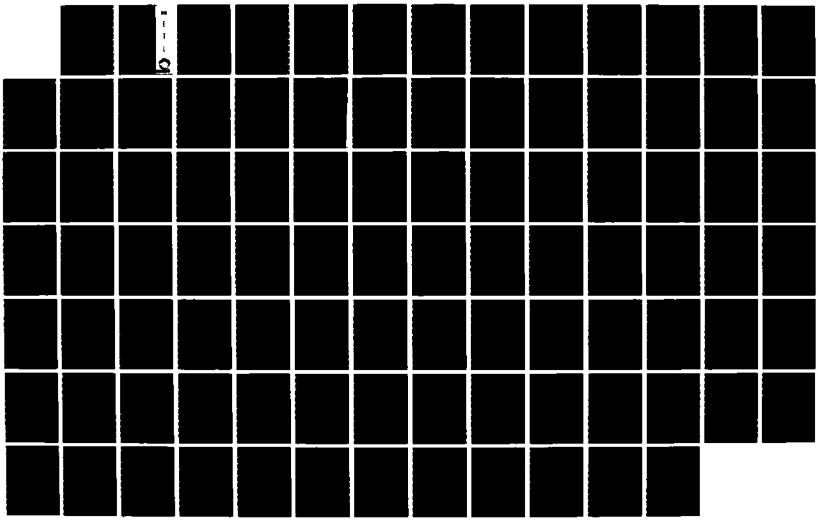

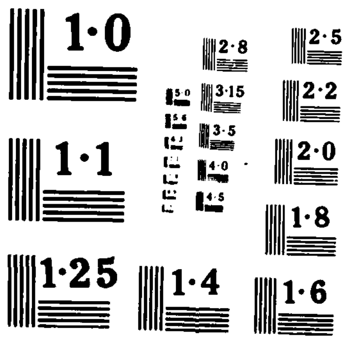
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World weather extremes

Pauline Riordan
Paul G. Bourget

December 1985

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E T L

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<u>ERRATUM:</u>

Top of page 26 should read as follows:

World's lowest temperature

$-89^{\circ}C$ ($-129^{\circ}F$)

Vostok, Antarctica, 21 July 1983

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Extremes	Precipitation (meteorology)	Humidity
Weather	Atmospheric pressure	Fog
Weather observations	Solar radiation	Thunderstorms
Meteorological charts	Wind (meteorology)	
Temperature	Weather intelligence	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report consists of a worldwide map of weather extremes and a separate map for the United States and Canada, with comments on the reliability of the records shown. Included are highest and lowest temperatures, largest temperature variations, greatest and least amounts of precipitation for various durations, maximum precipitation variabilities, greatest thunderstorm frequencies, highest and lowest atmospheric pressures, highest solar radiation, largest and heaviest hailstones, greatest snowfalls, highest wind speeds, high dew point, and most

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frequent occurrences of fog. Where appropriate, the value for the highest and lowest annual mean is also given. As far as possible, the records are taken from official sources, and all of them are documented. Conditions of site, instrumentation, observational procedure, and other factors such as environmental and meteorological conditions pertinent to the reliability of extremes are discussed.

PREFACE

In 1955 a map titled "World Weather Extremes" was prepared by the Cartography Branch of the Environmental Protection Research Division, Quartermaster Research and Engineering Center, Natick, Massachusetts, for distribution to visitors and other interested persons. This map showed the location of certain meteorological extremes that had been recorded in climatological publications. In subsequent years the map was periodically revised as new records came to light and the number of requests for it increased. It has been reprinted in a number of publications, both military and civilian, and has been widely used for instruction and display purposes. It has also been of use to preparers of standards and regulations concerned with meteorological and climatic limits that design criteria for military equipment must meet.

In 1970, during a periodic revision of the map, an explanatory text was added to provide some discussion of the records shown, as well as documentation of sources from which they were obtained. Also at that time, a map of weather extremes in North America was introduced. The text was issued as Weather Extremes Around the World, Technical Report 70-45-ES, of the Earth Sciences Laboratory of the U.S. Army Natick Laboratories.* In 1974 the maps and text were updated in a technical report (ETL-TR-74-5) issued by the U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia. As weather records are continuously broken and as use of metric units (not included in the previous reports) is increasing in the United States, another update has become necessary.

Valuable advice and information were received from Dr. M. A. Arkin, formerly of Environmental Data Service, National Oceanic and Atmospheric Administration (NOAA), for both of the previous reports. His assistance is acknowledged with appreciation. For this present publication acknowledgement is gratefully made to Gordon McKay and Frank Manning of Canada's Atmospheric

* The Earth Sciences Laboratory at Natick was transferred in 1971 and became a part of the U.S. Army Engineer Topographic Laboratories (ETL), Corps of Engineers, at Fort Belvoir, Virginia.

Environment Service, Canadian Climate Centre at Downsview, Ontario, for assistance with the Canadian records; and to J. de la Lande of Australia's Bureau of Meteorology, Victorian Regional Office in Melbourne, for assistance with the Australian records. Gratitude is also extended to all those who made suggestions or reviewed draft copies of the maps and text, especially to Robert J. Schmidli of the U.S. National Weather Service Forecast Office in Phoenix, Arizona (author of <u>Weather Extremes</u>); Dr. David M. Ludlum, founder of <u>Weatherwise</u>; Dr. Paul C. Dalrymple (now retired) of the U.S. Army Engineer Topographic Laboratories (ETL); Mr. Dale Johnson of the National Aeronautics and Space Administration (NASA); and Mr. Harold Feinstein of South Euclid, Ohio, who shared his research findings with us.

The cartography in the original report was completed at the Earth Sciences Laboratory at Natick. The maps have been recompiled for this report and are now printed in color. Dates of the extreme occurrences are added to the information on the reverse sides of the maps. Acknowledgement of cartographic assistance is gratefully made to the Cartographic/Reproduction Group of the Terrain Analysis Center at ETL and, most especially, to Ms. Carla Ennis for her outstanding contributions. Appreciation for cartographic assistance is also gratefully extended to Harry Jansohn and the National Graphic Center, Falls Church, Virginia. Appreciation for word processing support is given to Ms. Josefina Arroyo of ETL.

This report was prepared under DA project QG68550, Task D, Work Unit 02, "Environmental Design Guidance and Evaluation."

The work was accomplished under the supervision of Dr. Donald W. Dery, Group Chief, Battlefield Environmental Effects Group; Regis J. Orsinger, Chief, Land Combat Systems Division; and Bruce K. Opitz, Director, Geographic Sciences Laboratory.

COL Alan L. Laubscher, CE was Commander and Director and Mr. Walter E. Boge was Technical Director of the U.S. Army Engineer Topographic Laboratories during the report preparation.

WORLD WEATHER EXTREMES

CONTENTS

WORLD WEATHER EXTREMES

I. INTRODUCTION

A. Subject. The world map and the map of Canada and the United States were prepared primarily as aids in specifying extreme climatic conditions for design of military equipment. The two maps together contain approximately 100 records. This report is intended to review the validity of these records. A listing of the records, with documentation of sources, is followed by a commentary on their reliability.

Following comment on the representativeness and significance of weather records in general, each of the weather extremes is considered in turn. Among the factors discussed are measuring instruments and problems of measurement, environmental conditions that favor the occurrence of extremes, theoretical limits of occurrence, and the geographical areas and seasons in which the probability of extremes is greatest. Pertinent information is given about individual records and their documentation. Although there is much information available about some of the extremes, especially controversial ones, there is little or no information about others. Similarly, records are more easily available for the United States and Canada than for other countries. To make room for showing these records, and because Americans would be especially interested in records of these two countries, a separate map of the United States and Canada has been included.

In the two previous reports, the records were coordinated wherever possible with the determinations of the U.S. National Oceanic and Atmospheric Administration's Environmental Data Service (EDS). In the United States this agency was responsible for archiving and disseminating weather data, and in line with these functions it formerly validated extreme occurrences, both at

home and abroad.[1] This practice of validating extreme occurrences has, however, been discontinued. There is, as far as we have been able to determine, no world agency that validates and establishes a register of weather extremes.

B. Documentation. To facilitate finding the extremes for a particular element, the records are listed and documented by elements in the table following the two maps. Records for each element are arranged in order of decreasing extremity, beginning with the world's record where one is available. For some elements, only records for North America or for the United States are available; and for some types of extreme occurrences, record values have not been determined. These types (as well as records that are not officially validated) are included to indicate the limits that can be approached, and they are differentiated both on the maps and in the text by having their place names appear first.

[1] M.A. Arkin, Chief, Foreign Branch, Environmental Data Service, U.S. Environmental Science Services Administration, letter dated September 10, 1969.

WORLD WEA

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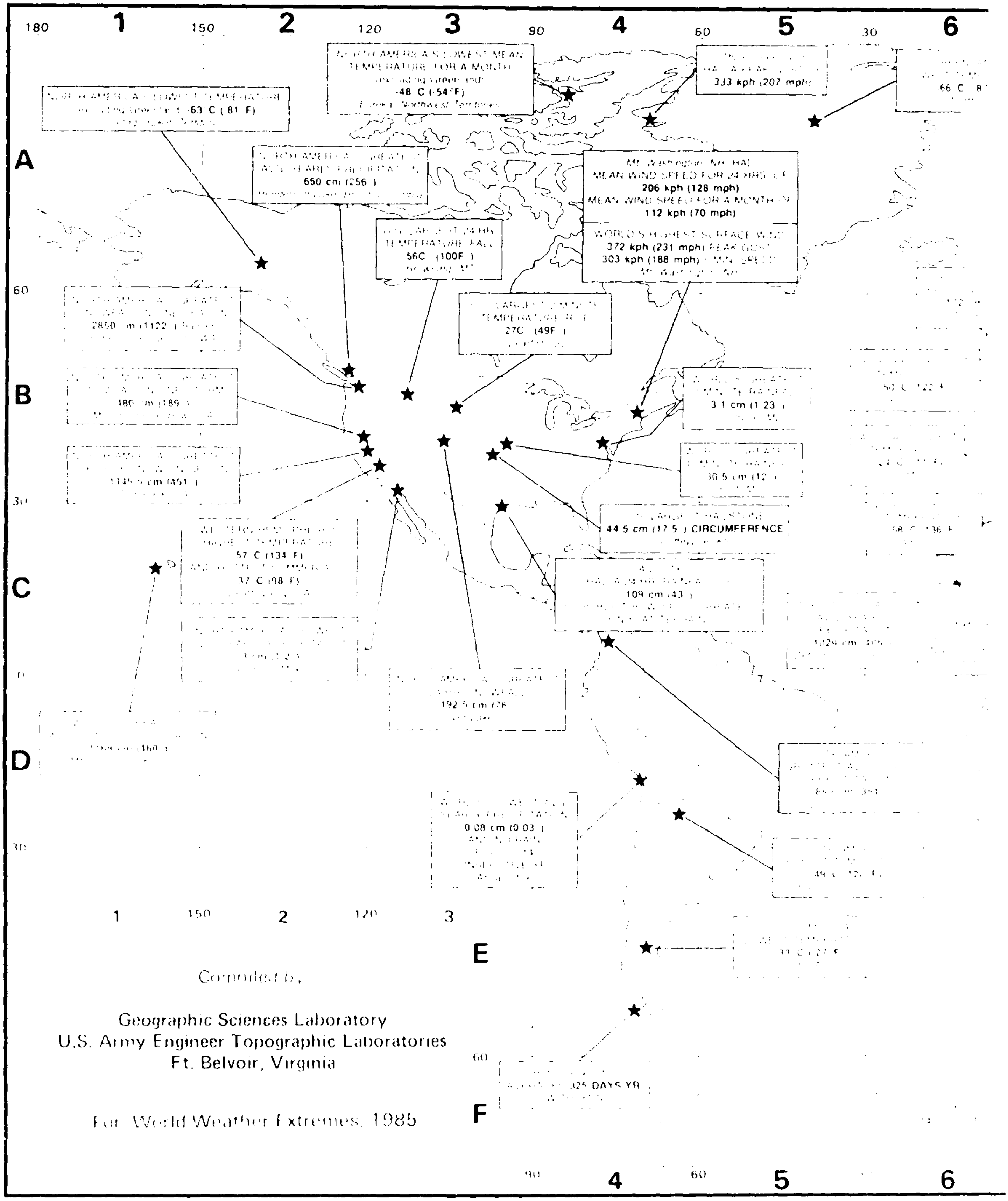

THER EXTREMES

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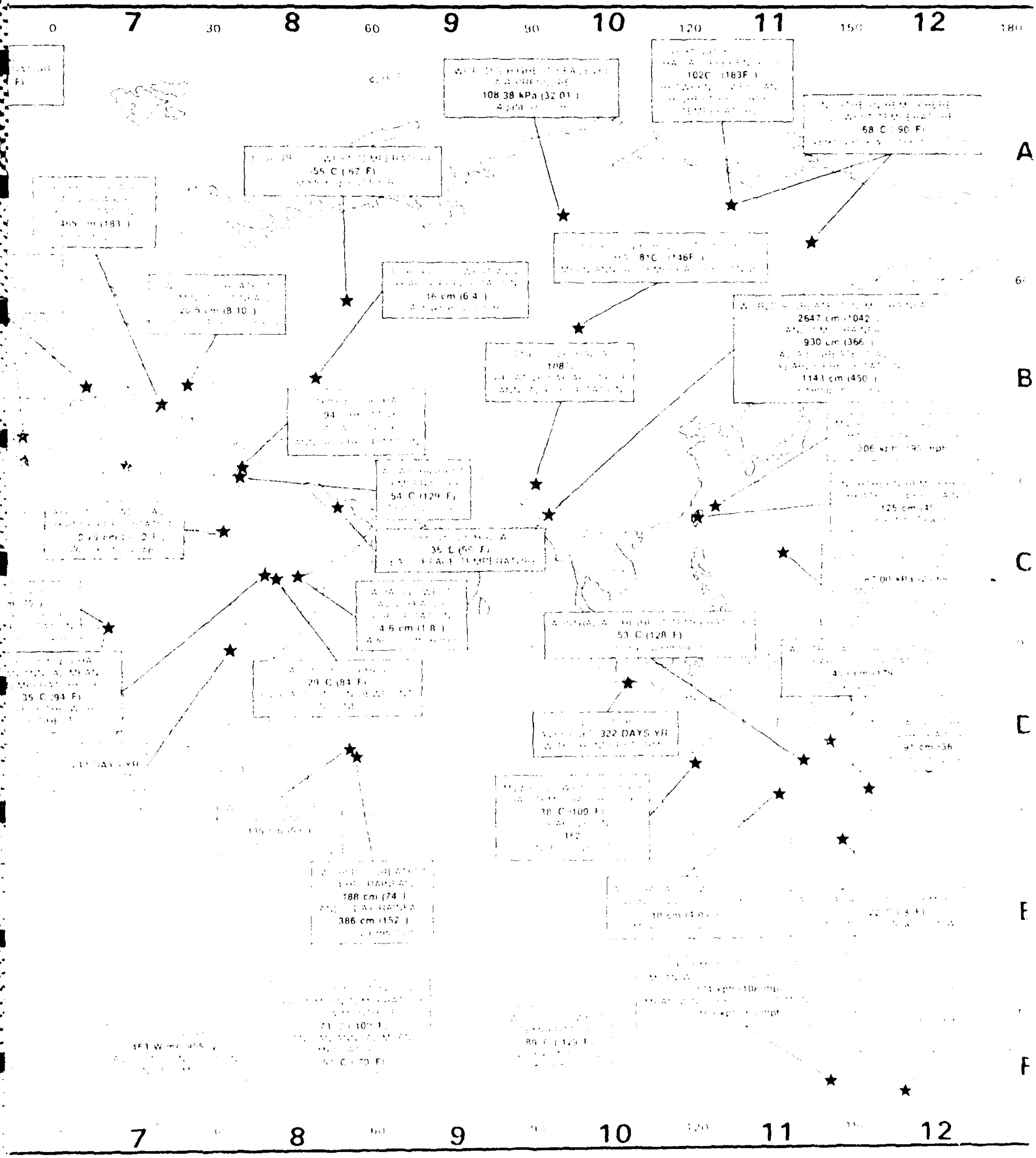

I TEMPERATURE

A High

World El Azizia Libya 13 September 1922 B7
Western Hemisphere Death Valley, California 10 July 1913 B3
Asia Tirat Tsvi Israel 21 June 1942 B8
Australia Cloncurry Queensland 16 January 1889 D11
Europe Seville Spain 4 August 1881 B6
South America Rivadavia Argentina 11 December 1905 D5
Antarctica Vanda Station 5 January 1974 F12
South Pole 27 December 1978 F6
Sea surface Persian Gulf 5 August 1924 C8
Annual mean Dallol Ethiopia October 1960 to December 1966 C8
Hottest summers Western Hemisphere Death Valley, California 1941 to 1971 B3
Long hot spell Marble Bar Western Australia 30 October 1923 to 7 April 1924 D10

B Low

World Vostok Antarctica 21 July 1983 F10
Northern Hemisphere Verkhoyansk & Oimekon U.S.S.R. 5 and 7 February 1892 and 6 February 1933 A11
Greenland Northice 9 January 1954 A5
North America excluding Greenland Snag Yukon Territory 3 February 1947 A2
Europe Ust Shchugor U.S.S.R. January (date not known, lowest in 15 year period) B8
South America Sarmiento Argentina 1 June 1907 F4
Africa Ifrane Morocco 11 February 1935 B6
Australia [illegible] New South Wales 14 June 1945 and 22 July 1947 E11
Annual mean [illegible] Station Antarctica 1958 to 1963 F8
[illegible] Plateau Station Antarctica July 1968 F8
[illegible] North America excluding Greenland Eureka Northwest Territories February [illegible] A4

C [illegible]

[illegible] Verkhoyansk U.S.S.R. A11
[illegible] Region of U.S.S.R. B10
[illegible] Spearfish South Dakota 22 January 1943 B3
[illegible] Browning Montana 23 and 24 January 1916 B3

II PRECIPITATION

A [illegible]

[illegible] Maryland 4 July 1956 B4
[illegible] Rockport, Romania 7 July 1889 B7
[illegible] Missouri 22 June 1947 B3
[illegible] Reunion 25 and 26 February 1964 D8
24 [illegible] Reunion 15 and 16 March 1952 D8
24 [illegible] Paishih Taiwan 10 and 11 September 1963 [illegible]
24 [illegible] Texas 25 and 26 July 1979 B3
24 [illegible] Australia [illegible] Queensland 3 February 1893 [illegible]
[illegible] Reunion 15 to 18 March 1952 D8
[illegible] World Cherrapunji [illegible] 1861 [illegible]
[illegible] World Cherrapunji [illegible] August 1860 to August 1861 [illegible]

ER EXTREMES BY ELEMENT - WORLD MAP

B Great Average Yearly Precipitation

World Mt Waialeale, Kauai, Hawaii, 32 year period C1
Asia Cherrapunji, India, 74-year period C10
Africa Debundscha, Cameroon, 32 year period C7
South America Quibdo, Colombia, 10 to 16 year period C4
North America Henderson Lake, British Columbia, 14 year period B2
Europe Crkvice, Yugoslavia 22 year period B7
Australia Tully, Queensland, 31 year period D11
Average number of days with rain per year Bahia Felix, Chile E4

C Least Precipitation

Number of years without rain Arica, Chile October 1903 to January 1918 D4

D Low Average Yearly Precipitation

World Arica, Chile, 59 year period D4
Africa Wadi Halfa, Sudan, 39 year period C8
North America Bataques, Mexico 14 year period B3
Asia Aden, South Yemen, 50 year period C8
Australia Mulka, South Australia, 34 year period D11
Europe Astrakhan U S S R , 25 year period B8

E Variability of Precipitation

Average variability Debundscha, Cameroon C7
Relative variability Themed, Israel 1921 to 1947 B8
Relative variability Lhasa Tibet 1935 to 1939 C10

F Hailstones

Largest, U S Coffeyville Kansas, 3 September 1970 B3

G Great Snowfall Amounts

24 hour North America Silver Lake Colorado 14 and 15 April 1921 B3
19 hour Bessans France, 5 and 6 April 1969 B7
One storm North America Mt Shasta Ski Bowl California 13 to 19 February 1959 B2
One season North America Rainier Paradise Ranger Station, Washington 1971 and 1972 B2
Greatest depth on ground North America Tamarack California 11 March 1911 B3

[illegible] OTHER ELEMENTS

A Thunderstorms

Average number of thunderstorm days per year Kampala Uganda 10-year period C8
Average number of thunderstorm days per year Bogor, Indonesia 1916 to 1920 D10

B Sea Level Air Pressure

Highest World Agata U S S R 31 December 1968 A10
Lowest World estimated in area of 17 N 138 E 12 October 1979 C11

C Solar Radiation

Average daily insolation December South Pole Antarctica 1958 to [illegible] F2

D Wind Speed

Peak gust World Mt Washington New Hampshire 12 April 1934 B4
Peak gust Thule Greenland 8 March 1972 A4
Peak gust Miyakojima I Ryukyu Islands 5 September [illegible] C11
5 minute World Mt Washington New Hampshire 12 April 1934 B4
Mean for 24 hours Mt Washington New Hampshire 11 and 12 April 1934 B4
Mean for 24 hours Port Martin Antarctica 21 and 22 March 1951 F11
Mean for 1 month Mt Washington New Hampshire February 1939 B4
Mean for 1 month Port Martin Antarctica March 1951 F11

E Dew Point

Mean afternoon in June Assab [illegible] C8

WEATHER EXTREMES IN CANADA AND

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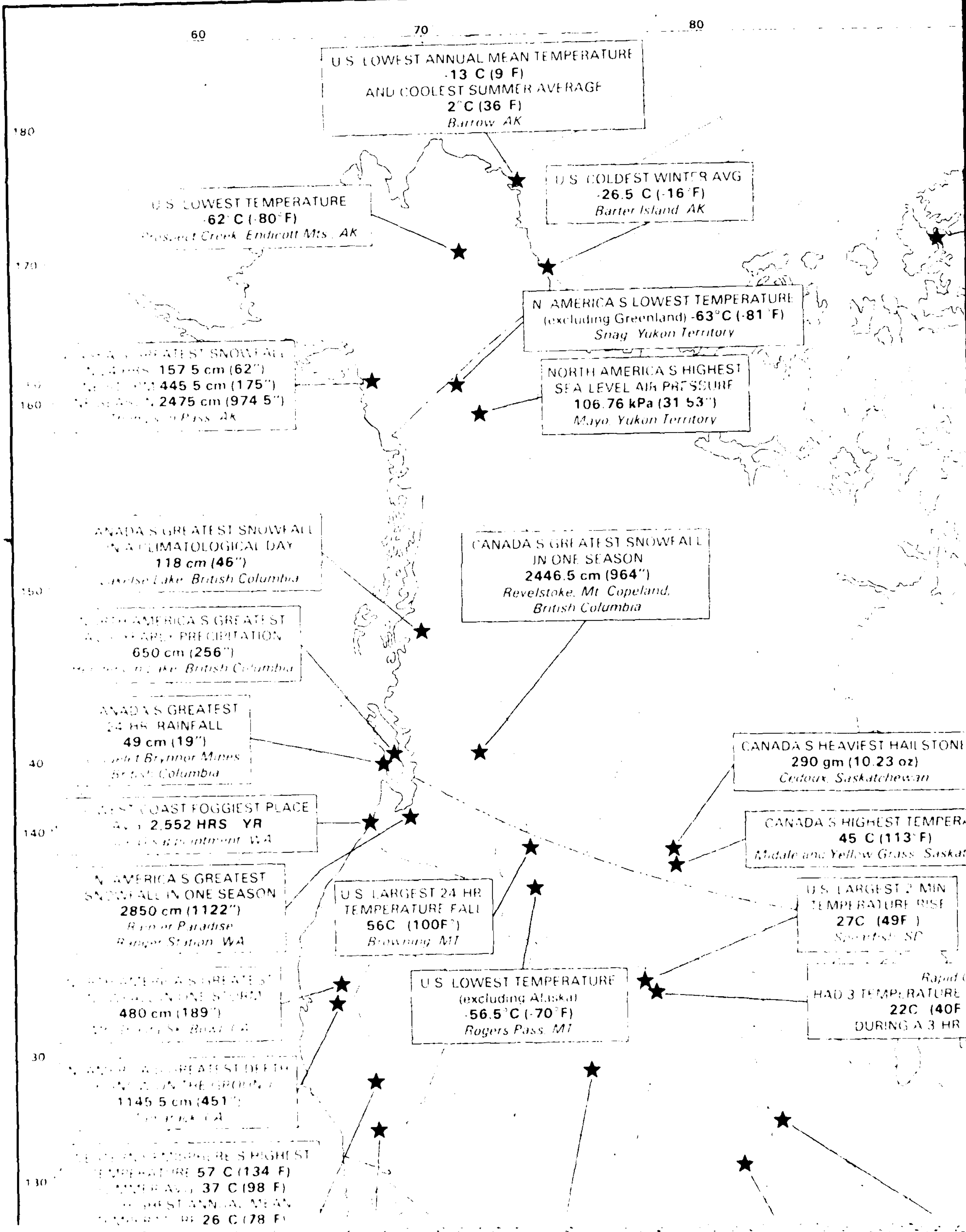

ANADA AND THE UNITED STATES

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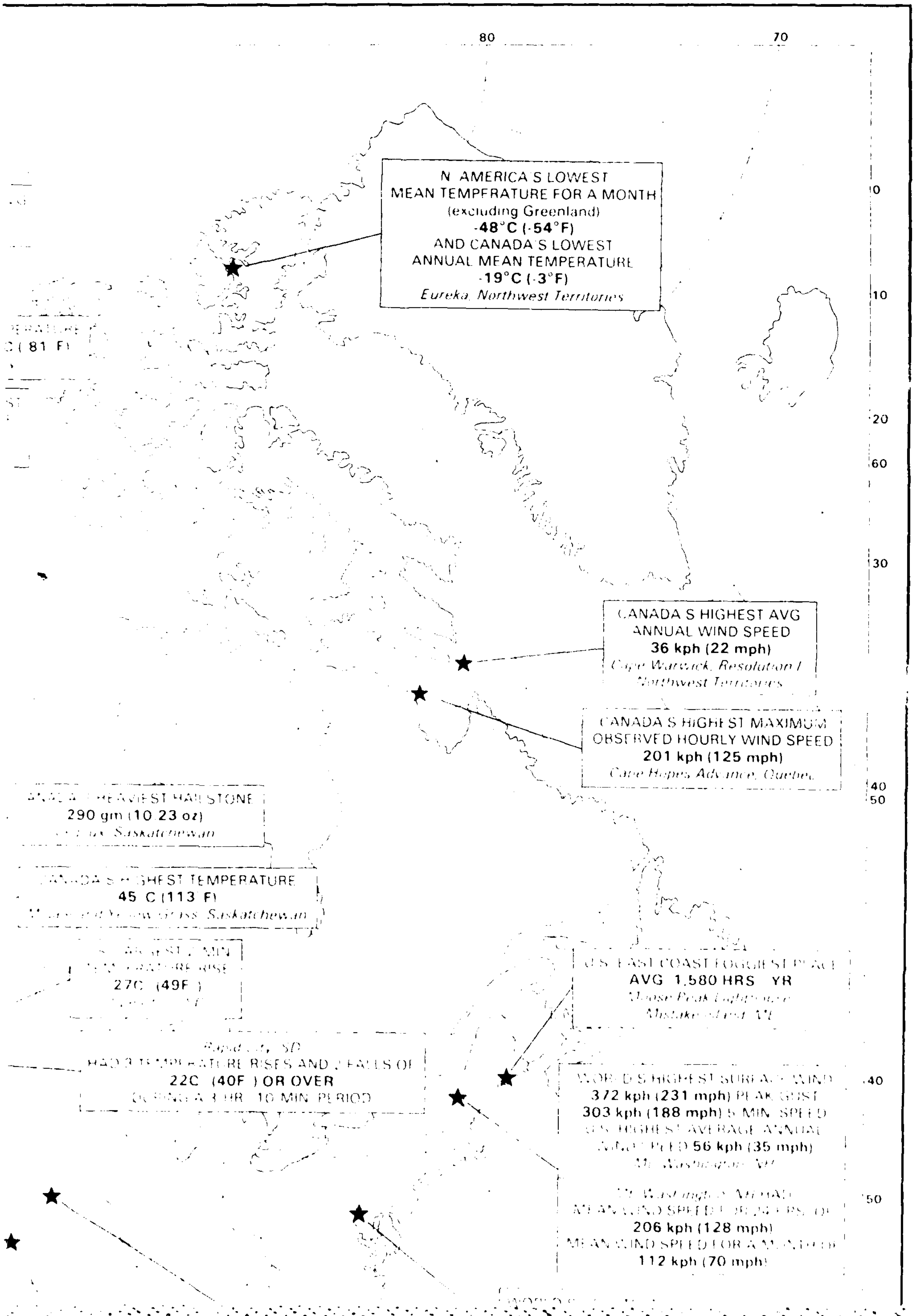
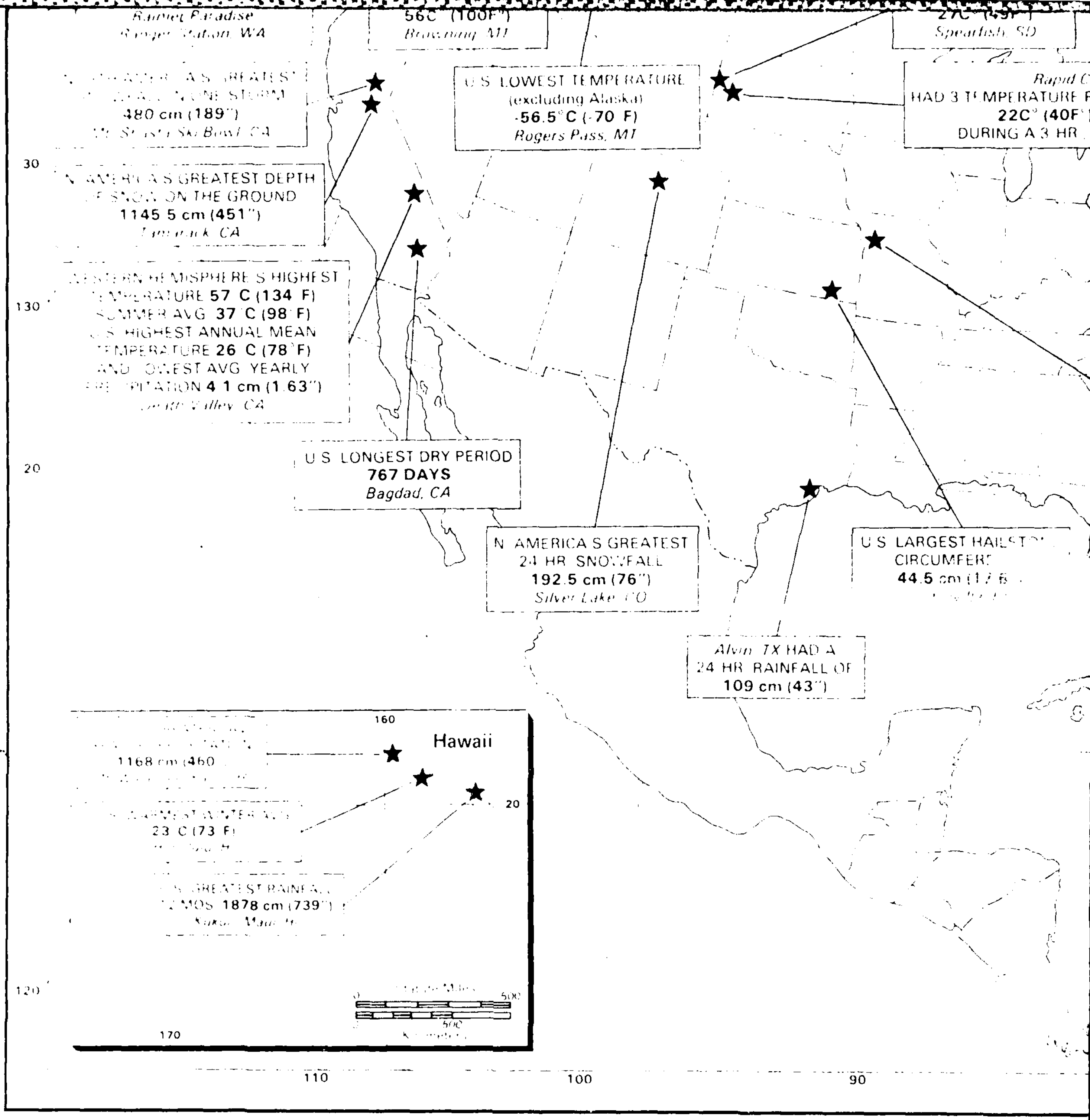
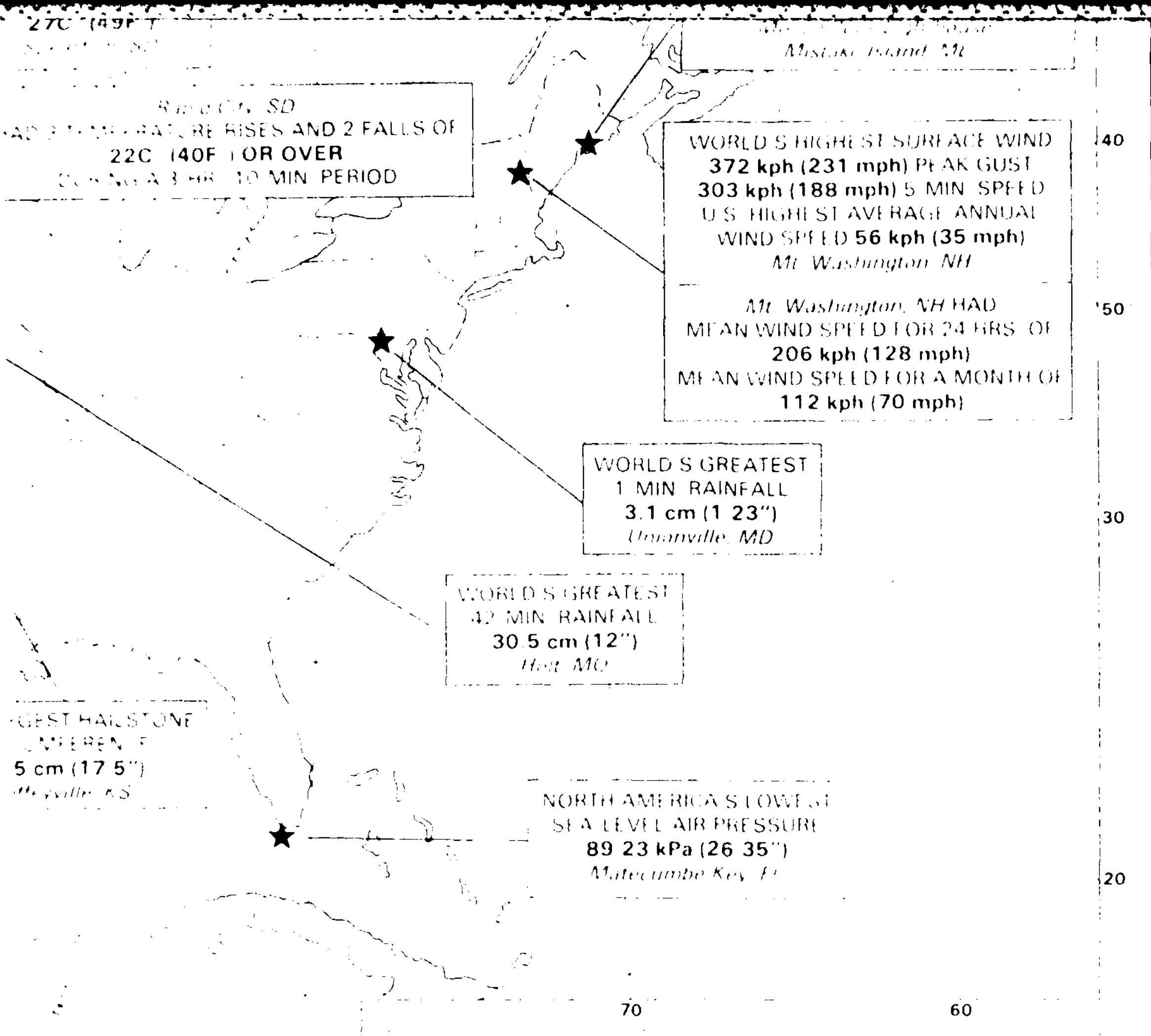




Rainier Paradise
Ranger Station, WA
56C° (100F°)
Browning, MT
27C° (49F°)
Spearfish, SD
U S LOWEST TEMPERATURE
(excluding Alaska)
-56.5°C (-70 F)
Rogers Pass, MT
Rapid C
HAD 3 TEMPERATURE R
22C° (40F°)
DURING A 3 HR
480 cm (189")
Mt Shasta Ski Bowl CA
GREATEST DEPTH
ON THE GROUND
1145 5 cm (451")
Tamarack CA
HEMISPHERE S HIGHEST
TEMPERATURE 57 C (134 F)
SUMMER AVG 37 C (98 F)
HIGHEST ANNUAL MEAN
TEMPERATURE 26 C (78 F)
AND LOWEST AVG YEARLY
PRECIPITATION 4 1 cm (1.63")
Death Valley CA
U S LONGEST DRY PERIOD
767 DAYS
Bagdad, CA
N AMERICA S GREATEST
24 HR SNOWFALL
192.5 cm (76")
Silver Lake CO
Alvin TX HAD A
24 HR RAINFALL OF
109 cm (43")
U S LARGEST HAILSTONE
CIRCUMFERENCE
44.5 cm
Hawaii
1168 cm (460
23 C (73 F)
GREATEST RAINFALL
12 MOS 1878 cm (739")
160
20
120
170
30
130
110
100
90



Compiled by

Geographic Sciences Laboratory
U.S. Army Engineer Topographic Laboratories
Ft. Belvoir, Virginia

For: World Weather Extremes, 1985

WEATHER EXTREMES BY ELEMENT - CANADA AND THE UNITED STATES

I TEMPERATURE

A High

Western Hemisphere Death Valley, California, 10 July 1913
Canada Midale and Yellow Grass, Saskatchewan, 5 July 1937
Annual mean, U S Death Valley, California, 1941 to 1971
Hottest summers, Western Hemisphere Death Valley, California, 1941 to 1971
Warmest winters, U S Honolulu, Hawaii, 1941 to 1971

B Low

North America (excluding Greenland) Snag, Yukon Territory, 3 February 1947
U S Prospect Creek, Endicott Mts , Alaska, 23 January 1971
U S (excluding Alaska) Rogers Pass, Montana, 20 January 1954
Annual mean, Canada Eureka, Northwest Territories, 1947 to 1980
Annual mean, U S Barrow, Alaska, 1941 to 1971
Mean for a month, North America (excluding Greenland) Eureka Northwest Territories, February 1979
Coldest winters, U S Barter Island, Alaska, 1941 to 1971
Coolest summers, U S Barrow, Alaska, 1941 to 1971

C Variations

Largest 2-minute rise, U S Spearfish, South Dakota, 22 January 1943
Largest 24 hour fall, U S Browning, Montana, 23 and 24 January 1916
Rapid fluctuations Rapid City, South Dakota 22 January 1943

II PRECIPITATION

A Great Rainfall Amounts

1 minute, World Unionville, Maryland, 4 July 1956
42-minute, World Holt, Missouri, 22 June 1947
24 hour Alvin, Texas, 25 and 26 July 1979
24 hour, Canada Ucluelet Brynnor Mines, British Columbia, 6 October 1967
12-month, U S Kukui, Maui, Hawaii, December 1981 to December 1982
Average yearly, World, Mt Waialeale, Kauai, Hawaii, 32 year period
Average yearly, North America Henderson Lake British Columbia, 14-year period

B Least Precipitation

Long dry spell Bagdad, California, 3 October 1912 to 8 November 1914

C Low Average Yearly Precipitation

U S Death Valley California 1911 to 1953

D Hailstones

Largest, U S Coffeyville, Kansas, 3 September 1970
Heaviest Canada Cedoux, Saskatchewan, 27 August 1973

E Great Snowfall Amounts

24-hour, North America Silver Lake, Colorado, 14 and 15 April 1921
24 hour, Alaska Thompson Pass, 29 December 1955
Climatological day, Canada Lakelse Lake, British Columbia, 17 January 1974
One storm, North America Mt Shasta Ski Bowl, California, 13 to 19 February 1959
One storm, Alaska Thompson Pass, 26 to 31 December 1955
One season, North America Rainier Paradise Ranger Station, Washington, 1971 - 1972
One season, Alaska Thompson Pass, 1952 - 1953
One season, Canada Revelstoke, Mt Copeland British Columbia, 1971 - 1972
Greatest depth of snow on ground, North America Tamarack, California, 11 March 1911

III OTHER ELEMENTS

A Sea Level Air Pressure

Highest North America Mayo Yukon Territory, 1 January 1974
Lowest, North America Matecumbe Key, Florida, 2 September 1935

B Wind Speed

Peak gust World Mt Washington, New Hampshire 12 April 1934
5 minute, World Mt Washington, New Hampshire 12 April 1934
Maximum observed hourly wind speed, Canada Cape Hopes Advance, Quebec 18 November 1931
Mean for 24 hours Mt Washington, New Hamphshire 11 and 12 April 1934
Mean for month Mt Washington, New Hampshire, February 1939
Average annual U S Mt Washington, New Hampshire 1934 to 1983
Average annual Canada Cape Warwick, Resolution Island, Northwest Territories, 1962 to 1973

C Fog Frequency

Average hours per year U S West Coast Cape Disappointment Washington 10 year period or more
Average hours per year U S East Coast Moose Peak Lighthouse Mistake Island Maine 10 year period or more

Table 1. Weather Records By Element, With Documentation

Element	Reference
1. Temperature	
A. Highest	
World, 58°C (136°F), El Azizia, Libya, 13 September 1922	R.J. Schmidli, Weather Extremes, Revised, Salt lake City, Utah, U.S. National Oceanic and Atmospheric Administration, National Weather Service, Western Region, December 1983. (NOAA Technical Memorandum NWS WR-28).
Western Hemisphere, 57°C (134°F), Death Valley, California, 10 July 1913	Ibid.
Asia, 54°C (129°F), Tirat Tsvi, Israel, 21 June 1942	U.S. Environmental Science Services Administration, Environmental Data Service, Worldwide Extremes of Temperature, Precipitation and Pressure Recorded by Continental Area (ESSA/P1680032), October 1968.
Australia, 53°C (128°F), Cloncurry, Queensland, 16 January 1889	Ibid.
Europe, 50°C (122°F), Seville, Spain, 4 August 1881	Ibid.
South America, 49°C (120°F), Rivadavia, Argentina, 11 December 1905	Ibid.
Canada, 45°C (113°F), Midale and Yellow Grass, Saskatchewan, 5 July 1937	F.D. Manning, Climatic Extremes for Canada, Canada. Atmospheric Environment Service, Downsview, Ontario, 1983, (CLI-3-83).
Vanda Station, Antarctica, had a 15°C (59°F) maximum, 5 January 1974 (possibly Antarctica's highest)	New Zealand Antarctic Society, Inc., "Antarctic Heat Wave", Antarctic, Vol. 7, No. 1. p. 4, March 1974.

South Pole, $-14^{\circ}C$ ($7.5^{\circ}F$), 27 December 1978	U.S. National Science Foundation, Division of Polar Programs, "New Temperature High for South Pole", Antarctic Journal of the United States, Vol. XIV, No.1, p. 8, March 1979.
Persian Gulf had a $36^{\circ}C$ ($96^{\circ}F$) sea-surface, 5 August 1924	U.S. Environmental Science Services Administration, Environmental Data Service, Temperature Extremes, Revised May 1967 (L.S. 5821).

B. Highest Average

Dallol, Ethiopia, has a $35^{\circ}C$ ($94^{\circ}F$) annual mean, from October 1960 to December 1966 (possibly the world's highest)	D.E. Pedgley, "Air Temperatures at Dallol, Ethiopia", Meteorol Mag., London, Vol. 96, No. 1142, pp. 265-71, 1967.
U.S., highest annual mean, $26^{\circ}C$ ($78^{\circ}F$) from 1941 to 1971, Death Valley, California	U.S. National Oceanic and Atmospheric Administration, Environmental Data and Information Service, Temperature Extremes in the United States, Revised, (Environmental Information Summaries C-5), Asheville, N.C., National Climatic Center, June 1979.
Western Hemisphere, hottest summers, $37^{\circ}C$ ($98^{\circ}F$) average from 1941 to 1971, Death Valley, California	Ibid.
U.S., warmest winters, $23^{\circ}C$ ($73^{\circ}F$) average from 1941 to 1971, Honolulu, Hawaii	Ibid.
Marble Bar, West Australia, had temperatures of $38^{\circ}C$ ($100^{\circ}F$) or above on 162 consecutive days, 30 October 1923 to 7 April 1924	H.T. Ashton and J.V. Maher, Australian Forecasting and Climate, 6th ed., Melbourne, Australia, 1960.

C. Lowest

World, $-89^{\circ}C$ ($-129^{\circ}F$), Vostok, Antarctica, 21 July 1983	R.J. Schmidli, op. cit.
Northern Hemisphere, $-68^{\circ}C$ ($-90^{\circ}F$), Verkhoyansk, U.S.S.R., 5 and 7 February 1892 and Oimekon, U.S.S.R., 6 February 1933	Ibid.

Greenland, $-66^{o}C$ $(-87^{o}F)$, Northice, 9 January 1954	*Ibid.*
North America, excluding Greenland, $-63^{o}C$ $(-81^{o}F)$, Snag, Yukon Territory, 3 February 1947	*Ibid.*
U.S., $-62^{o}C$ $(-80^{o}F)$, Prospect Creek, Endicott Mts., Alaska, 23 January 1971	D.M. Ludlum, *Weather Record Book, U.S. and Canada*, Weatherwise, *Princeton, New Jersey, 1971.*
U.S., excluding Alaska, $-56.5^{o}C$ $(-70^{o}F)$, Rogers Pass, Montana, 20 January 1954	U.S. National Oceanic and Atmospheric Administration, Environmental Data and Information Service, *op. cit.*
Europe, $-55^{o}C$ $(-67^{o}F)$, Ust 'Shchugor, U.S.S.R., January (date not known, lowest in 15-year period)	U.S. Environmental Science Services Administration, Environmental Data Service, *Worldwide Extremes of Temperature, Precipitation and Pressure Recorded by Continental Area*, *op. cit.*
South America, $-33^{o}C$ $(-27^{o}F)$, Sarmiento, Argentina, 1 June 1907	*Ibid.*
Africa, $-24^{o}C$ $(-11^{o}F)$, Ifrane, Morocco, 11 February 1935	*Ibid.*
Australia, $-22^{o}C$ $(-8^{o}F)$, Charlotte Pass, New South Wales, 14 June 1945 and 22 July 1947	*Ibid.*

D. Lowest Average

Plateau Station, Antarctica, had an annual mean of $-57^{o}C$ $(-70^{o}F)$ from 1966 to 1969	P.C. Dalrymple, Geographic Sciences Laboratory, U.S. Army Engineer Topographic Laboratories, Fort Belvoir, VA, Personal Communication.
Canada, lowest annual mean, $-19^{o}C$ $(-3^{o}F)$ from 1947 to 1980, Eureka, Northwest Territories	D.W. Phillips and D. Aston, "A Record Cold Month in North America", *Weatherwise*, Vol. 33, No. 1, pp. 24-25, February 1980.
U.S., lowest annual mean, $-13^{o}C$ $(9^{o}F)$ from 1941 to 1971, Barrow, Alaska	U.S. National Oceanic and Atmospheric Administration, Environmental Data and Information Service, *op. cit.*
Plateau Station, Antarctica, had a mean for a month of $-73^{o}C$ $(-100^{o}F)$, July 1968	P.C. Dalrymple, *op. cit.*

North America, lowest mean for a month (excluding Greenland), -48°C (-54°F), Eureka, Northwest Territories, February 1979	D.W. Phillips and D. Aston, *op. cit.*
U.S., coldest winters, -26.5°C (-16°F) average from 1941 to 1971, Barter Island, Alaska	U.S. National Oceanic and Atmospheric Administration, Environmental Data and Information Service, *op. cit.*
U.S., coolest summers, 2°C (36°F) average from 1941 to 1971, Barrow, Alaska	*Ibid.*

E. Temperature Variations

Verkhoyansk, U.S.S.R., has a difference of 102C° (183F°) between lowest (-67.6°C, -89.7°F) and highest (34.2°C, 93.5°F) recorded temperatures	S.P. Suslov, *Physical Geography of Asiatic Russia*, transl. by N.D. Gershevsky and ed. by J.E. Williams, W.H. Freeman, San Francisco, 1961.
Canada, greatest difference between lowest (-62.2°C, -80°F) and highest (36.1°C, 97°F) recorded temperatures, 98C° (177F°), Mayo, Yukon Territory*	H. Feinstein, letter dated 20 February 1985; M. Newark, "Canadian Weather Extremes", *Chinook*, Vol. 6, No. 3, pp. 76-78, Summer 1984.
Eastern Sayan Region of U.S.S.R. has 81C° (146F°) mean annual temperature range, from -47.3°C (-53.2°F) to 34°C (93.2°F)	*Ibid.*
U.S., largest 2-minute temperature rise, 27C° (49F°), from -20°C (-4°F) to 7°C (45°F), Spearfish, South Dakota, 22 January 1943	U.S. National Oceanic and Atmospheric Administration, Environmental Data and Information Service, *op. cit.*
U.S., largest 24-hour temperature fall, 56C° (100F°), from 6.7°C (44°F) to -49°C (-56°F), Browning, Montana, 23-24 January 1916	*Ibid.*
Rapid City, South Dakota, had three temperature rises and two falls of 22C° (40F°) or over during a period of 3 hours, 10 minutes, 22 January 1943	R.R. Hamann, "The Remarkable Temperature Fluctuations in the Black Hills Region", January 1943, *Monthly Weather Rev*, Vol. 71, No. 3, pp. 29-32, March 1943.

* Record received too late for mapping

II. Precipitation

A. Greatest Rainfall

World, 1-minute, 3.1 cm (1.23"), Unionville, Maryland, 4 July 1956	J.L.H. Paulhus, "Indian Ocean and Taiwan Rainfalls Set New Records", Monthly Weather Rev, Vol. 93, No. 5, pp. 331-35, May 1965.
World, 20-minute, 20.5 cm (8.10"), Curtea-de-Arges, Romania, 7 July 1889	Ibid.
World, 42-minute, 30.5 cm (12"), Holt, Missouri, 22 June 1947	Ibid.
World, 12-hour, 135 cm (53"), Belouve, La Réunion I., 28-29 February 1964	Ibid.
World, 24-hour, 188 cm (74"), Cilaos, La Réunion I., 15-16 March 1952	Ibid.
Northern Hemisphere, 24-hour, 125 cm (49"), Paishih, Taiwan, 10-11 September 1963	Ibid.
Australia, 24-hour, 91 cm (36"), Crohamhurst, Queensland, 3 February 1893 (updated to 114 cm or 44", Bellenden Ker, Queensland, 4 January 1979)*	B.W. Newman, "Australia's Highest Daily Rainfall", Australian Meteorol Mag, No. 20, pp. 61-65, March 1958; J. de la Lande, Australia.Bureau of Meteorology, Victorian Regional Office, Melbourne, Victoria, Correspondence dated 5 July 1985.
Alvin, Texas, had a 24-hour rainfall of 109 cm (43"), 25-26 July 1979 (possibly the world's greatest on flat terrain)	R.J. Schmidli, op. cit.
Canada, 24-hour, 49 cm (19"), Ucluelet Brynnor Mines, British Columbia, 6 October 1967	F.D. Manning, op. cit.
World, 5-day, 386 cm (152"), Cilaos, La Réunion I., 13-18 March 1952	J.L.H. Paulhus, op. cit.
World, 1-month, 930 cm (366"), Cherrapunji, India July 1861	Ibid.

* Record received too late for mapping

World, 12-month, 2647 cm (1042"), Cherrapunji, India, August 1860 to August 1861	Ibid.
U.S., 12 month, 1878 cm (739"), Kukui, Maui, Hawaii, December 1981 to December 1982	U.S. National Oceanic and Atmospheric Administration, National Climatic Center, *Climatological Data Annual Summary Hawaii & Pacific* 1981, Vol. 77, No. 13; National Climatic Data Center, *Annual Summary Hawaii & Pacific* 1982, Vol. 78, No. 13, Asheville, N.C., 1982, 1983.

B. Greatest Average Yearly Precipitation

World, 1168 cm (460") during a 32-year period, Mt. Waialeale, Kauai, Hawaii	U.S. Environmental Science Services Administration, Environmental Data Service, *Worldwide Extremes of Temperature, Precipitation and Pressure Recorded by Continental Area*, *op. cit.*
Asia, 1143 cm (450") during a 74-year period, Cherrapunji, India	Ibid.
Africa, 1029 cm (405") during a 32-year period, Debundscha, Cameroon	Ibid.
South America, 899 cm (354") during a 10-16 year period, Quibdó, Colombia	M.A. Arkin, Chief, Foreign Branch, Environmental Data Service, U.S. Environmental Science Service Administration, Correspondence dated 6 October 1969.
North America, 650 cm (256") during a 14-year period Henderson Lake, British Columbia	F.D. Manning, Canada. Atmospheric Environment Service, Canadian Climate Centre, Downsview, Ontario, Correspondence dated 30 June 1984 and Telephone Communication, 11 July 1984.
Europe, 465 cm (183") during a 22-year period, Crkvice, Yugoslavia	U.S. Environmental Science Services Administration, Environmental Data Service, *Worldwide Extremes of Temperature, Precipitation and Pressure Recorded by Continental Area*, *op. cit.*
Australia, 455 cm (179") during a 31-year period, Tully, Queensland (updated to 425 cm (167") during a 59-year period)*	Ibid.; J. de la Lande, *op. cit.*

* Record received too late for mapping

Bahia Felix, Chile, averages 325 days/year with rain	L.H. Seamon and G.S. Bartlett, "Climatological Extremes", *Weekly Weather and Crop Bull*, Vol. 43, No. 9, pp. 6-8, 27 February 1956.
Canada, highest frequency of days with precipitation, 242 per year average, Langara, Queen Charlotte Islands, British Columbia*	M. Newark, *op. cit.*

C. Least Precipitation

Arica, Chile, had no rain for more than 14 consecutive years, October 1903 to January 1918	R.J. Schmidli, *op. cit.*
U.S., longest dry period, 767 days from 3 October 1912 to 8 November 1914, Bagdad, California	L.H. Seamon and G.S. Bartlett, *op. cit.*
Canada, least precipitation during a calendar year, 1.27 centimeters (0.05 inches), Arctic Bay, Northwest Territories, 1949*	M. Newark, *op. cit.*
Canada, lowest frequency of days with precipitation, 8 per year average, Rea Point, Northwest Territories*	*Ibid.*

D. Lowest Average Yearly Precipitation

World, 0.08 cm (0.03") during a 59-year period, Arica, Chile	U.S. Environmental Science Services Administration, Environmental Data Service, *Worldwide Extremes of Temperature, Precipitation and Pressure Recorded by Continental Area*, *op. cit.*
Africa, <0.25 cm (<0.1") during a 39-year period, Wadi Halfa, Sudan	*Ibid.*
North America, 3.0 cm (1.2") during a 14-year period, Bataques, Mexico	*Ibid.*

* Record received too late for mapping

U.S., 4.1 cm (1.63") during a 42-year period, Death Valley, California	M.A. Arkin, op. cit.; U.S. Weather Bureau, Climatic Summary of the United States--From the Establishment of Stations to 1930 Inclusive and Supplement for 1931-1952, Section 18, Southern California and Owens Valley, Washington, D.C., GPO, 1932, 1953.
Asia, 4.6 cm (1.8") during a 50-year period, Aden, South Yemen	U.S. Environmental Science Services Administration, Environmental Data Service, Worldwide Extremes of Temperature, Precipitation and Pressure Recorded by Continental Area, op. cit.
Australia, 10 cm (4.05") during a 34-year period, Mulka, South Australia (updated to during a 42-year period, Troudaninna, South Australia)*	Ibid; J. de la Lande, op. cit.
Europe, 16 cm (6.4") during a 25-year period, Astrakhan, U.S.S.R.	Ibid.

E. Variability of Precipitation

Debundscha, Cameroon, has 191 cm (75") average variability of annual precipitation	E. Biel, "Die Veränderlichkeit der Jahressumme des Niederschlags auf der Erde" [The Variability of the Yearly Amount of Precipitation of the Earth], Geographische Jahrbuch aus Oesterreich, Leipzig, Vols 14-15, pp. 151-80, 1929.
Themed, Israel, has a 94% relative variability of annual precipitation, from 1921 to 1947	J. Katsnelson and S. Kotz, "On the Upper Limits of Some Measures of Variability", Archiv für Meteorol, Geophysik und Bioklimatol, Ser. B., Vol. 8, pp. 103-107, 1958.
Lhasa, Tibet, had a 108% relative variability of annual precipitation, from 1935 to 1939	A. Lu, "A Brief Survey of the Climate of Lhasa", Quarterly J Roy Meteorol Soc, Vol. 65, No. 281, pp. 297-302, 1939.

F. Hailstones

U.S., largest hailstone, 44.5 cm (17.5") circumference, Coffeyville, Kansas, 3 September 1979	"The 'New Champ' Hailstone", Weatherwise, Vol. 24, No. 4, p. 151, 1971.

* Record received too late for mapping

Canada, heaviest hailstone, 290 gm (10.23 oz), Cedoux, Saskatchewan, 27 August 1973	L. Wojtiw and E.P. Lozowski, "Record Canadian Hailstone", Amer Meteorol Soc Bull, Vol. 56, No. 12, pp. 1275-76, December 1975.
Canada, highest frequency of days with hail, 7 per year average, Edson and Red Deer, Alberta*	M. Newark, op. cit.

G. Greatest Snowfall

North America, 24-hour, 192.5 cm (76"), Silver Lake, Colorado, 14-15 April 1921	R.J. Schmidli, op. cit.
Alaska, 24-hour, 157.5 cm (62"), Thompson Pass, 29 December 1955	Ibid.
Bessans, France, had a snowfall of 172 cm (68") in 19 hours, 5-6 April 1969	M. Jail, "Un remarquable effet de lombarde: les chutes de neige de Paques 1969 en Haute-Maurienne", Revue de Geographie Alpine, Grenoble, Vol. 57, No. 3, pp. 613-21, 1969.
Canada, climatological day, 118 cm (46"), Lakelse Lake, British Columbia, 17 January 1974	F.D. Manning, Climatic Extremes for Canada, op. cit.
North America, one storm, 480 cm (189"), Mt. Shasta Ski Bowl, California, 13-19 February 1959	R.J. Schmidli, op. cit.
Alaska, one storm, 445.5 cm (175"), Thompson Pass, 26-31 December 1955	Ibid.
North America, one season, 2850 cm (1122"), Rainier Paradise Ranger Station, Washington, 1971-1972	"New U.S. Record Snowfall", Weatherwise, Vol. 25, No. 4, p. 173, 1972.
Alaska, one season, 2475 cm (974.5"), Thompson Pass, 1952-1953	R.J. Schmidli, op. cit.
Canada, one season, 2446.5 cm (964"), Revelstoke Mt. Copeland, British Columbia, 1971-1972	F.D. Manning, Climatic Extremes for Canada, op. cit.
Canada, highest frequency of days with snow, 142 per year average, Old Glory Mountain, British Columbia*	M. Newark, op. cit.

* Record received too late for mapping

North America, greatest depth of snow on the ground, 1145.5 cm (451"), Tamarack, California, 11 March 1911	R.J. Schmidli, *op. cit.*
Canada, greatest depth of snow on the ground, 775 cm (305"), Loch Lomond, British Columbia*	M. Newark, *op. cit.*

III. Other Elements

A. Thunderstorms

Kampala, Uganda, averages 242 days/year with thunderstorms, during a 10-year period	World Meteorological Organization, *World Distribution of Thunderstorm Days*, (OMM, No. 21), Geneva, Switzerland, 1953.
Bogor, Indonesia, averaged 322 days/year with thunderstorms from 1916 to 1920	V.I. Arabadzhi, "Klimat i grozy" [Climate and Thunderstorms], *Priroda*, No. 2, pp. 65-66, 1966. (Translated by E.R. Hope as Canada. Defence Research Board Translation T456R, April 1966).
Canada, highest frequency of days with thunderstorms, 34 per year average, Windsor, Ontario*	M. Newark, *op. cit.*

B. Sea-Level Air Pressure

World, highest, 108.38 kPa (32.01"), Agata, U.S.S.R., 31 December 1968	"Extremes of Atmospheric Pressure", *Weatherwise*, Vol. 24, No. 3, pp. 130-31, 1971.
North America, highest, 106.76 kPa (31.53"), Mayo, Yukon Territory, 1 January 1974	R.J. Schmidli, *op. cit.*
World, lowest, 87.00 kPa (25.69"), by dropsonde in eye of Typhoon Tip (16°44'N.137°46'E.), 12 October 1979	*Ibid.*

* Record received too late for mapping

North America, lowest, 89.23 kPa (26.35"), Matecumbe Key, Florida, 2 September 1935	Ibid.
C. Solar Radiation	
South Pole has 463 W/m^2 (955 ly) average daily insolation in December, from 1958 to 1966	U.S. Environmental Science Services Administration, Environmental Data Service, Climatological Data for Antarctica Stations, Nos. 1 and 9, Washington, D.C., GPO, 1962, 1968.
Canada, greatest number of hours of sunshine during a month, 621 (83% of total possible), Eureka, Northwest Territories, May 1973*	M. Newark, op. cit.
D. Wind Speed	
World, highest peak gust, 372 kph (231 mph), Mt. Washington, New Hampshire, 12 April 1934	U.S. National Oceanic and Atmospheric Administration, National Climatic Data Center, Local Climatological Data; Annual Summary with Comparative Data, 1982, Mount Washington Observatory, Gorham, New Hampshire, Asheville, N.C., 1983.
Thule, Greenland, had a peak gust of 333 kph (207 mph), 8 March 1972	J.R. Stansfield, "The Severe Arctic Storm of 8-9 March 1972 at Thule Air Force Base, Greenland", Weatherwise, Vol. 25, No. 5, pp. 228-33, 1972.
Miyakojima I., Ryukyu Islands, had a peak gust of 306 kph (190 mph), 5 September 1966	Y. Mitsuta and S. Yoshizumi, "Characteristics of the Second Miyakojima Typhoon", Kyoto, Japan, Univ. Disaster Prevention Research Institute. Bulletin, Vol. 18, pt. 1, No. 131, pp. 15-34, 1968.
World, highest 5-minute, 303 kph (188 mph), Mt. Washington, New Hampshire, 12 April 1934	R.J. Schmidli, op. cit.
Canada, highest maximum observed hourly, 201 kph (125 mph), Cape Hopes Advance, Quebec, 18 November 1931	F.D. Manning, Canada. Atmospheric Environment Service, Canadian Climate Centre, Downsview, Ontario, Telephone Communications, 7 March 1984 and 11 July 1984.

* Record received too late for mapping

Mt. Washington, New Hampshire, had a mean for 24 hours of 206 kph (128 mph), 11-12 April 1934	S. Pagliuca *et. al.*, "The Great Wind of April 11-12, 1934 on Mt. Washington, N.H., and its measurement", *Monthly Weather Rev*, Vol. 62, pp. 186-89, June 1934.
Port Martin, Antarctica, had a mean for 24 hours of 174 kph (108 mph), 21-22 March 1951	F. Loewe, "The Land of Storms", *Weather*, Vol. 27, No. 3, pp. 110-21, 1972.
Mt. Washington, New Hampshire, had a mean for a month of 112 kph (70 mph), February 1939	*Mount Washington Observatory News Bulletin*, No. 12, p. 23, September 1943.
Port Martin, Antarctica, had a mean for a month of 105 kph (65 mph), March 1951	F. Loewe, *op. cit.*
U.S., highest average annual, 56 kph (35 mph) from 1934 to 1983, Mt. Washington, New Hampshire	M.A. Arkin, *op. cit.*; U.S. National Oceanic and Atmospheric Administration, National Climatic Data Center, *Local Climatological Data; Annual Summary with Comparative Data, 1967, Mount Washington Observatory, Gorham, New Hampshire*, *op. cit.*
Canada, highest average annual, 36 kph (22 mph) from 1962 to 1973, Cape Warwick, Resolution Island, Northwest Territories	A.P. Georgiades, "Canada's Highest Wind Speeds", *J Meteorol*, Vol. 2, No. 20, pp. 264-66, June/July 1977.

E. Dew Point (Humidity)

Assab, Ethiopia, has 29°C (84°F) average afternoon dew point in June	A.V. Dodd, *Areal and Temporal Occurrence of High Dew Points and Associated Temperatures*, U.S. Army Natick Laboratories, Natick, Massachusetts, Technical Report ES-49, August 1969.

F. Fog Frequency

U.S. West Coast, highest average, 2552 hours per year during a 10-year period or more, Cape Disappointment, Washington	M.A. Arkin, *op. cit.*
U.S. East Coast, highest average, 1580 hours per year during a 10-year period or more, Moose Peak Lighthouse, Mistake Island, Maine	*Ibid.*
Canada, highest average, 158 days per year, Cape Race, Newfoundland*	M. Newark, *op. cit.*

* Record received too late for mapping

II. RELIABILITY OF WEATHER RECORDS

A. RECORDS. To ensure comparability of meteorological observations, various regulations concerning site, instrumentation, and procedure have been established by the World Meteorological Organization.[2] Observations taken in accordance with these regulations, over which some sort of quality control is exercised to correct observational errors that might appear, would be accepted by the national meteorological agencies.[3] Also, for highest or lowest average records, the period of observation should be long enough to be representative. However, even after records have been accepted by appropriate agencies, their reliability is still sometimes questioned.

An extreme phenomenon observed and recorded in conformance with prescribed procedures and accepted by the appropriate meteorological service represents only the most extreme acceptable record that is available. It is not necessarily -- or even probably -- the most extreme value that could occur or ever has occurred. According to M.A. Arkin, "...record extremes must be taken with a grain of salt...."[4] He explains that news of an extreme weather occurrence is not always widely disseminated, meteorological records are relatively short, stations are very few, and "...even the densest network of stations provides only a very small sample of the weather..."[5] To this it can be added that records may be established which the observers do not recognize as records, and sometimes suspected records are not verified because of difficulties in validating.

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[2] World Meteorological Organization, Guide to Meteorological Instruments and Observing Practices, 4th ed., Geneva (WMO No. 8, TP. 3), 1971.

[3] M.A. Arkin, op. cit.

[4] Ibid.

[5] Ibid.

B. TEMPERATURE. Air temperatures are measured at standard heights varying in different countries from 1.2 to 1.8 meters (4 to 6 feet) above ground level. The values obtained can be affected by radiation from the sun, sky, earth, and other surrounding objects, and precautions need to be taken to protect the measuring instruments from radiation. Also, adequate ventilation must be provided to ensure representation of the circulating air. In addition to these requirements concerning height, radiation protection, and ventilation, there are requirements pertinent to construction and accuracy (manufacturing tolerance) of the measuring instruments.

Daily maximum and minimum temperatures are recorded at more than 10,000 weather stations throughout the world.[6] Maximum and minimum thermometers that stay at the highest or the lowest point, respectively, reached during the reading period are used to record these temperatures. Maximum thermometers are generally of the mercury-in-glass type, but since mercury freezes at about $-36^{o}C$ ($-32^{o}F$), minimum thermometers contain other liquids such as ethyl alcohol. These are commonly called spirit thermometers because of the type of liquids used.

Besides the absolute maximum and minimum temperatures ever recorded in an area, several other kinds of extreme temperature records can be of interest. Among these are the highest and the lowest mean daily, monthly, or yearly temperatures; the highest and the lowest mean daily, monthly, or yearly maximum and minimum temperatures; the longest durations of very high or very low temperatures; the greatest variations in a given period (e.g. between summer and winter, day and night); and the fastest rises and falls in temperature during short periods of time.

a. High Temperature. Factors favorable to occurrence of very high

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[6] G. Hoffmann, "Die hochsten und die tiefsten Temperaturen auf der Erde" [The Highest and the Lowest Temperatures of the Earth], Umschau, Frankfurt am Main, Vol. 63, No 1, pp. 16-18, 1 Jan 63.

temperatures have been listed by the British meteorologist H.H. Lamb.[7] Among these factors are strong heating of the surface, especially desert sand or bare rock, during times of high sun and very clear atmosphere; a long period of time during which the air has passed or remained over an extremely warm surface; inhibition of vertical convection or local circulations by subsidence; passage of the air over mountains, especially when latent heat absorbed during condensation or rainfall on the ascent is released into the descending air; and advection from places where the air was already heated.

Lamb's investigations suggest that conjunction of most or all of these influences might occur during record high extremes and that many of the peak temperatures "...are associated with the speeding up, and longer fetch, of warm air advection just ahead of a cold front...." Further, he concludes that these extreme high temperatures "...may have been very local and associated with some locally forced turbulence -- for instance, in air descending some sort of declivity or merely passing over town buildings -- the circumstances being such as to raise adiabatically by a degree or two the temperature of already very warm air at a slightly higher level...."[8]

The highest possible temperature that could occur has been considered by the German meteorologist G. Hoffmann.[9] According to him, because warm air is lighter, air near the hot ground surface seeks to rise above overlying layers that are cooler. Thus, an ascending air stream is established through which the hot air escapes so that the temperature of the lower levels should not rise above a theoretically definable value. He puts this value at slightly over 55°C (131°F) and states that world weather observations confirm it. The highest accepted record is 58°C (136°F) at El Azizia in North Africa, but claims have been made of higher temperatures, e.g. 60°C (140°F)

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[7] H.H. Lamb, "The Occurrence of Very High Surface Temperatures", Meteorol Mag, London, Vol. 87, No. 1028, pp. 39-43, 1958.

[8] Ibid.

[9] G. Hoffmann, op. cit.

at two Mexican stations, Delta, Baja California, and Riito, Sonora.[10] It should be pointed out that a thermometer exposed to the sun, especially on barren or rocky ground or pavement, would give readings considerably higher than the officially reported shade temperatures. It is not uncommon for surface temperatures of the ground or of objects exposed to the sun to exceed El Azizia's 136°F. Maximum soil-surface temperatures recorded in various parts of the world have been tabulated by Jen-hu Chang.[11] Some of the temperatures were 59°C (138°F) and 63°C (145°F) in Vasterbotton and Siikakangas, Finland (both at 62°N.); 75°C (167°F) in Poona, India (at 18°N.); and 82°C (180°F) in Loango, Africa, at 4°39'S.11°48'E.

The highest mean yearly maximum temperatures, 50°C (122°F) or above, occur in the northern and western Sahara; Death Valley, California; low-lying desert areas in Iran; and a small part of western Pakistan.[12] By contrast, the highest yearly maximum temperatures in some parts of Antarctica average below -15°C (5°F).[13] The highest temperature ever recorded at the South Pole is -13.6°C (7.5°F) and at Vostok, -15.7°C (4°F).[14]

World's highest temperature
58°C (136°F)
El Azizia, Libya, 13 September 1922

El Azizia is located in the northern Sahara at 32°32'N.13°01'E., eleva-

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[10] International Boundary and Water Commission, United States and Mexico, "Flow of the Colorado River and Other Western Boundary Streams and Related Data", p. 58, Western Water Bulletin, 1964.

[11] J.H. Chang, Ground Temperature, Vol. I, p. 94, Blue Hill Meteorological Observatory, Harvard University, Milton, Mass., 1958.

[12] G. Hoffmann, op. cit.

[13] Ibid.

[14] M.W. Sinclair, "Record High Temperatures in the Antarctic - A Synoptic Case Study", Monthly Weather Rev, Vol. 109, No. 10, pp. 2234-42, Oct 1981.

tion 112 meters (367 feet).[15] At least 30 years of observations are available for the station,[16] and the climate has been described by Eredia.[17] The world record temperature occurred during the month of September; other months during which very high maximum temperatures have occurred are August and June, with 56°C (133°F) and 53°C (127°F), respectively.[18]

Although this record of 58°C (136°F) has attained general acceptance as the world's highest temperature recorded under standard conditions,[19,20] it has been questioned. A. Fántoli, who was Director of the Libyan Meteorological Service at the time the observation was reported, has written about the subject[21,22] and summaries in English are available.[23,24] Although he was unable to investigate personally the reliability of the reading at the time it occurred, he did examine the evidence in some detail, such as the exposure; the effect of instrument shelter or of instrumental error; the

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[15] Great Britain. Air Ministry, Meteorological Office, Tables of Temperature, Relative Humidity and Precipitation for the World, Part IV, Africa, the Atlantic Ocean South of 35°N and the Indian Ocean, (M.O. 617d), 1925.

[16] Ibid.

[17] F. Eredia, "Klima von Azizia" [Climate of Azizia], Meteorol Zeitschrift, Braunschweig, Vol. 42, p. 294, 1925.

[18] Great Britain. Air Ministry, Meteorological Office, op. cit.

[19] U.S. Environmental Science Services Administration, Environmental Data Service, Temperature Extremes (L.S. 5821), Revised May 67.

[20] L.H. Seamon and G.S. Bartlett, "Climatological Extremes," Weekly Weather and Crop Bull, Vol. 43, No. 9, pp. 6-8, 27 Feb 56.

[21] A. Fántoli, "La Piu Alta Temperatura del Mondo," [The Highest Temperature in the World], Rev Meteorol Aeronautica, Rome, Vol. 18, No. 3, pp. 53-63, Jul-Sep 58. (English Summary).

[22] A. Fántoli, "I Valori Medi Della Temperatura in Libia", Boll Soc Geogr Italiana, ser. 8, Vol. 7, pp. 59-71, 1954.

[23] J. Gentilli, "Libyan Climate", Geograph Rev, Vol. 45, No. 2, p. 269, Apr 55.

[24] Meteorol Abstracts, 10(10), 1959, (Contains abstract of #18).

records for pressure, wind, and humidity at three other stations in Tripoli for 9-12 September 1922; and the synoptic charts for the area for 10-14 September 1922. He also reviewed temperature records at El Azizia for June to October 1914-1922, as well as the maximum temperatures, 37°C to 48°C (99°F to 118°F), at 10 places in Tripoli on 11-14 September 1922. From his investigations, Fántoli concluded that although there was an unusually violent and persistent ghibli[25] at the time, the probable or tentative maximum on 13 September 1922 was 56°C (132.8°F). This conclusion may have been influenced in part by the comparatively low maximum temperatures at nearby stations, a point also mentioned by other authors.[26]

Lamb also investigated the El Azizia record, and from his investigations he has described the synoptic situation that caused the extreme heat.[27] A cold front was advancing eastward from Algeria, and advection of warm air from the Saharan interior was established some distance ahead of the front. Tripoli had strong southerly winds for two successive days before the front passed. Also, latent heat of condensation might have been added to the air mass by rainfall which occurred as it passed over mountains in the Auderas area (17°N.8°E.) to the south of El Azizia.

Western Hemisphere's highest temperature
57°C (134°F)
Death Valley, California, 10 July 1913

Death Valley, at 37°N.117°W., is a desert, below sea level, flanked by mountains. It has the hottest summers in the Western Hemisphere and the

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[25] A ghibli is a hot, dust-bearing wind in Tripolitania.

[26] G. Hellmann, "Grenzwerte der Klimaelemente auf der Erde," [Limits of Climatic Elements of the Earth], Sitzungsberichte Preuss Akademie der Wissenschaft, Phys mathem, Klasse, 1925, pp. 200-215. Cited by Mark Jefferson: "Limiting Values of Temperature and Rainfall Over the World", Geograph Rev, Vol. 16, pp. 324-26, 1926.

[27] H.H. Lamb, op. cit.

highest annual mean temperature, 26°C (78°F), in the United States.[28] The temperature of 57°C (134°F), recorded at Greenland Ranch Station, is accepted by the U.S. Weather Bureau as an official record. On the day this temperature occurred, winds were strong, there were sandstorm conditions, and a heat spell of 8 consecutive days, with maximums of 53°C (127°F) or higher was in progress.[29]

A. Court[30] has examined the Death Valley record in detail. He examined the surrounding environment, the equipment and procedures used for taking the observation, the weather conditions at the time it occurred, and the temperature frequencies at the station over a period of record from 1911 through 1947. He found that at the time of the extreme temperature there were comparatively low maximums at other stations in the area, as had been the case at El Azizia. Also, he found that aside from the period during which the record occurred in July 1913, temperatures of 53°C (127°F) or higher were reached in only two other years from 1911 through 1947. (In July 1960, a temperature of 54°C, or 129°F, was reported[31], but according to Williams this value is doubtful.[32]) From his analysis of the 1911 through 1947 data, Court determined that a temperature of 57°C (134°F) has an expectancy of only once in 650 years.[33] Thus, he concluded that "constantly increasing accuracy in weather observations and higher standards of instrument exposure make it seem

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[28] U.S. National Oceanic and Atmospheric Administration, Environmental Data and Information Service, Temperature Extremes in the United States, Revised, National Climatic Center, Asheville, N.C. (Environmental Information Summaries C-5), June 1979.

[29] L. Williams, A Contribution to the Philosophy of Climatic Design Limits for Army Materiel: Extreme Hot-Desert Conditions, U.S. Army Engineer Topographic Laboratories, Fort Belvoir, VA., ETL-TR-72-5, June 1972, AO-A.

[30] A. Court, "How Hot is Death Valley?" Geograph Rev, Vol. 39, No. 2, pp. 214-20, Apr 49.

[31] P.I. Tattelman, N. Sissenwine and R.W. Lenhard, World Frequency of High Temperature, U.S. Air Force Cambridge Research Laboratories, Bedford, Mass., Environmental Research Papers, No. 305, 1969.

[32] L. Williams, op. cit.

[33] A. Court, op. cit.

probable that no future official observation will exceed the present high temperature record for North America now held by Death Valley".[34]

Persian Gulf had a sea-surface temperature of
36°C (96°F)
5 August 1924

This sea-surface temperature, measured by the SS Frankenfels, is "...among the highest recorded...."[35] However, sea-surface temperature in the Persian Gulf has been known to reach 37°C (98°F) in August and September.[36] Although the 36°C (96°F) record is not an absolute maximum in the sense of being the highest known, it was included here to indicate how hot the sea surface can become. The Persian Gulf also has very high average temperatures in summer, 31°C (88°F) during July and August.[37]

Dallol, Ethiopia, has an annual mean temperature of
35°C (94°F)
(possibly the world's highest)

Places that are hot in summer and remain warm in winter have high annual means of daily maximum temperature. The highest occur at low elevations, away from coasts, and within the latitude belt between 12° and 20°N across Africa and possibly in the southwestern Arabian peninsula.[38] Dallol is

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[34] *Ibid.*

[35] U.S. Environmental Science Services Administration, *Temperature Extremes*, *op. cit.*

[36] Great Britain. Air Ministry, Meteorological Office, *Weather in the Indian Ocean to Latitude 30°S and Longitude 95°E including the Red Sea and Persian Gulf*, volume II *Local Information* part 3, *The Persian Gulf and Gulf of Oman including the part of the Makran Coast west of Gwadar*, M.O. 451b), His Majesty's Stationery Office, London, 194[illegible].

[37] U.S. Environmental Science Services Administration, *Temperature Extremes*, *op. cit.*

[38] D.E. Pedgley, "Air Temperatures at [illegible]," *Meteorol. Mag*, London, Vol. 96, No. 1142, pp. [illegible].

within this belt at 14°19'N.40°11'E. It is located 79 meters (258 feet) below sea level on the edge of the Danakil Depression, a salt desert. By averaging the annual mean daily maximum temperature of 41°C (106°F)[39] and the annual mean daily minimum of 28°C (83°F),[40] an annual mean temperature of 35°C (94°F) is obtained. All of these values are possible world records. The 35°C (94°F) annual mean temperature exceeds the 31°C (88°F) averaged at Lugh Ferrandi, Somalia, from 1923 to 1935 and cited as probably the world's highest annual mean temperature.[41] The 41°C (106°F) annual mean daily maximum temperature exceeds the 39°C (102°F) recorded at Abecher, Chad, for a 6-year period and the 38°C (101°F) at Merowe, Sudan (39 years) and Araoune, Mali (8 years); these values are the highest listed in the British Meteorological Office's Tables of Temperature, Relative Humidity and Precipitation for the World.[42]

The Dallol temperatures were obtained from readings taken at a climatological station maintained at the base camp of an American prospecting company over a period of 6 years, October 1960 through November 1966. Maximum and minimum temperatures were recorded "...using standard thermometers kept at a height of four feet in a ventilated screen...."[43] Although the period of observation is short, it is believed that the difference between these available 6 year values and a long-term mean would be very small. At nearby Khormaksar, where temperature trends appear similar to Dallol's, the greatest difference between monthly means of daily maximum temperature for the years 1961 through 1966 and those for 1947 through 1966 was only 0.3°C (0.54°F).

D.E. Pedgley has considered areas where annual mean daily maximums might

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[39] Ibid.

[40] Ibid.

[41] U.S. Environmental Science Services Administration, Temperature Extremes, op. cit.

[42] Great Britain. Air Ministry, Meteorological Office, op. cit.

[43] D.E. Pedgley, op. cit.

equal or exceed Dallol's.[44] According to him, in the lowest part of the Danakil Depression, which reaches a minimum of about 119 meters (390 feet) below sea level some 20 miles south of Dallol, the annual mean daily maximum might be a "fraction of a degree Fahrenheit greater" than at Dallol. In the Abecher area where there is a "...descent of potentially warmer air resulting from a blocking by the Marra Mountains of the north-easterlies that blow for much of the year...", there might also be low-lying places with values similar to Dallol's.

Vanda Station, Antarctica
had a maximum temperature of
$15^{o}C$ ($59^{o}F$)
(possibly Antarctica's highest)

This reading was made at a research station of the New Zealanders on the shore of Lake Vanda at 77°32'S.161°40'E.[45] It was the highest temperature recorded there since the station was established in 1970, and it occurred during a period of record high temperatures in the McMurdo Sound and dry valley regions of the continent. The observation is officially accepted by the New Zealanders, but they hesitate to claim it as Antarctica's highest. However, it does surpass the record of $14^{o}C$ ($58^{o}F$) on 20 October 1956 at Esperanza on the Antarctic Peninsula,[46] which was used on previous maps of world weather extremes.

b. Low Temperatures. Extreme low temperatures result from "...the simultaneous occurrence of an optimum combination of several meteorological elements; absence of solar radiation, clear skies, and calm air are the most essential requirements, with the ultimate fall in temperature dependent

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[44] Ibid.

[45] New Zealand Antarctic Society, Inc., "Antarctic Heat Wave", Antarctic, Vol. 7, No. 1, p. 4, Mar 74.

[46] U.S. Environmental Science Services Administration, Environmental Data Service, Worldwide Extremes of Temperature, Precipitation, and Pressure Recorded by Continental Area (ESSA/PI680032), Oct 68.

upon the duration of these conditions...."[47] During such conditions, there is minimum mixing of the vertical air layers. As the ground surface loses heat through terrestrial radiation, the nearest air layers become cooled and consequently heavier than the layers above them.

Extremely cold temperatures occur in interior high latitude localities with clear skies, which are conducive to maximum terrestrial radiation, and with topographic features that afford protection from wind. Geographic areas of extreme cold are the Antarctic Continent, especially the eastern Antarctic Plateau (approximately 2,750 to 3,700 meters or 9,000 to 12,000 feet in elevation); the central part of the Greenland Icecap (approximately 2,500 to 3,000 meters or 8,200 to 9,800 feet in elevation); Siberia between 63° and 68°N and between 93° and 160°E (below 760 meters or 2,500 feet in elevation); and the Yukon basin of northwestern Canada and Alaska (below 760 meters or 2,500 feet in elevation).

Annual mean minimum temperature can range from approximately 27°C (80°F) in places like Dallol, Ethiopia, to a possible -90°C (-130°F) in the Antarctic. This difference of 117 Celsius (210 Fahrenheit) degrees is considerably greater than the difference between the highest and lowest annual mean maximum temperatures. Annual mean minimums for the world's coldest areas are -60°C (-76°F) in Siberia, below -65°C (-85°F) on the Greenland Icecap, and from about -70°C to -90°C (-94°F to -130°F) in the Antarctic.[48] The -90°C (-130°F) value is considered possible as an annual mean minimum, even though -89.2°C (-128.6°F) is the lowest temperature recorded, because in the extensive cold area of East Antarctica only a few stations have taken temperature measurements and then only for short periods of time.[49]

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[47] R.A. McCormick, "An Estimate of the Minimum Possible Surface Temperature at the South Pole", Monthly Weather Rev., Vol. 86, No. 1, pp. 1-5, Jan 58.

[48] G. Hoffmann, op. cit.

[49] Ibid.

$-89^{\circ}C$ ($-129^{\circ}F$)

Vostok, Antarctica, 21 July 1983

The theoretical minimum temperature that could be reached has been calculated by Shliakhov[50] and by McCormick.[51] Shliakhov estimated $-80 \pm 2^{\circ}C$ at about 4 kilometers altitude (i.e. $-112^{\circ}F$ at about 13,123 feet) with a decrease of $0.5^{\circ}C$ for every further 100-meter rise in height. This estimate has been exceeded at Vostok ($78^{\circ}27'$S.$106^{\circ}52'$E., elevation 3,420 meters or 11,220 feet) and elsewhere on the Antarctic Plateau. In the winter of 1983, a new world record of $-89.2^{\circ}C$ ($-128.56^{\circ}F$) was reported from Vostok and confirmed by the Arctic and Antarctic Research Institute at Leningrad, U.S.S.R. An account of it has appeared, reportedly, in the Information Bulletin of the Soviet Antarctic Expedition, Number 105. This new record is included in Robert J. Schmidli's most recent Weather Extremes[52] and was also quoted to us by David M. Ludlum, founder of Weatherwise. The previous world record, also at Vostok, was $-88^{\circ}C$ ($-126.9^{\circ}F$) on 24 August 1960.[53]

The basic error in Shliakhov's calculations, according to H. Wexler,[54] resulted from associating a zero radiation balance with a certain temperature -- the theoretical minimum. McCormick's calculation for the possible minimum was for "...virtually optimum conditions...assumed to persist during the polar night (about 180 days)...."[55] The resultant value, $-200^{\circ}C$ ($-328^{\circ}F$),

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[50] V.I. Shliakhov, "O Minimal'nykh Temperaturakh v Antarktide" [On Minimum Temperatures in Antarctica], Meteorologiia i Gidrologiia, No. 4, pp. 5-7, 1958.

[51] R.A. McCormick, op. cit.

[52] R. J. Schmidli, Weather Extreme, Revised, Salt Lake City, Utah, U.S. National Oceanic and Atmospheric Administration, National Weather Service, Western Region, (NOAA Technical Memorandum NWS WR-28), Dec 83.

[53] U.S. Environmental Science Services Administration, Temperature Extremes, op. cit.

[54] H. Wexler, "Note on Lowest Antarctic Temperature Estimated by Shliakhov", Monthly Weather Rev, Vol. 87, No. 4, p. 147, Apr 59.

[55] R.A. McCormick, op. cit.

might be more applicable to the ozonosphere where such "...energy-balancing processes are not equally operative...."[56] An ozonospheric temperature of -97°C (-143°F) was measured at about 24,000 meters (78,740 feet) above Halley Bay at 75°31'S.26°36'W., altitude 30 meters (98 feet), on 9 August 1959.[57] The lowest temperature recorded in the Earth's atmosphere is -153°C (-243°F) at 93 kilometers (58 miles) above Point Barrow, Alaska, in June 1966.[58] However, this is above the ozonosphere, and June is not the time of polar night at Point Barrow.

Northern Hemisphere's lowest temperature
-68°C (-90°F)
Verkhoyansk, U.S.S.R., 5 and 7 February 1892
and Oimekon, U.S.S.R., 6 February 1933

Very low winter temperatures occur in the Verkhoyansk-Oimekon cold zone, approximately between 63° and 68°N., and 93° and 160°E. in the East Siberian taiga (northern coniferous forest). It is an area of extreme continentality, lying near the eastern end of the world's largest landmass and blocked off by mountain ranges from the moderating influence of oceans. In winter the high air pressures from the Asiatic anticyclone create clear weather, which promotes strong radiation from the snow surface during the long nights. A value of -67.6°C (-89.7°F) was recorded at Verkhoyansk (67°34'N.133°51'E., elevation 107 meters or 350 feet); and -67.7°C (-89.9°F) was recorded at Oimekon (63°28'N.142°49'E., elevation 806 meters or 2,625 feet).[59] Oimekon is a village of about 600 people in northeastern Yakutia. It is situated in a valley 10 to 20 kilometers (about 3,280 feet) wide, below a plateau which is, in turn, enclosed by mountains.[60] In the winter, cold air accumulates in the valley and there is hardly any wind. It is very

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[56] Ibid.

[57] D.J. George, "Coldest Place on Earth", Weather, Vol. 16, No. 5, pp. 144-50, 1961.

[58] H. Faust, "Die niedrigsten Temperaturen in der Erdatmosphäre" [The Lowest Temperatures in the Earth's Atmosphere], Weltraumfahrt, Frankurt am Main, Vol. 20, No. 1/2, pp. 25-27, 1969.

[59] U.S. Environmental Science Services Administration, Temperature Extremes, op. cit.

[60] A.A. Borisov, Climates of the U.S.S.R., translated by R.A. Ledward and edited by C.A. Halstead, Aldine, Chicago, 1965.

possible that the temperatures there may have fallen below the value recorded; temperatures of -70.5°C (-95°F) and down to -78°C (-108°F) have been claimed.[61,62,63] Considerable controversy has arisen about the records at Verkhoyansk because of problems concerning instrument corrections and about records at both Verkhoyansk and Oimekon because of misleading references to incorrect values in the literature.[64,65,66]

Greenland's lowest temperature

-66°C (-87°F)

Northice, 9 January 1954

On the permanent icecap, which covers most of the interior of Greenland, temperatures are very low because of loss of heat through radiation and evaporative cooling from the snow and ice surface.[67] A temperature of -66°C (-86.8°F) has been recorded at Northice (78°04'N.38°29'W., elevation 2,341 meters or 7,687 feet), a station established by the British North Greenland Expedition.[68] Temperatures below -59°C (-75°F) occurred 16 times. Since the period of record for Northice was only 20 months (November 1952 through June 1954), it is quite probable that temperatures there have been

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[61] N.A. Stepanova, "On the Lowest Temperature on Earth," Monthly Weather Rev, Vol. 86, No. 1, pp. 6-10, Jan 58.

[62] L.H. Seamon and G.S. Bartlett, op. cit.

[63] E.A. Finn, Kak Byl Otkryt "Polius Kholoda" [How was the "Cold Pole" Discovered?], Priroda, No. 7, pp. 85-88, Moscow, Jul 67.

[64] N.A. Stepanova, op. cit.

[65] E.S. Rubinshtein, "O Prirode Poliusov Kholoda" [On the Nature of the Cold Poles], Vsesoiuznoe Geograficheskoe Obshchestvo Izvestiia, Vol. 91, No. 3, pp. 265-68, May-Jun 59.

[66] E.S. Rubinshtein, "K Voprosu o Poliusakh Kholoda" [Contribution to the Problems of the Earth's Cold Poles], Meteorologiia i Gidrologiia, No. 12, pp. 28-30, Dec 1968, Translated by U.S. Weather Bureau, Washington, D.C., May 59.

[67] D.W. Hogue, Environment of the Greenland Icecap, U.S. Army Natick Laboratories, Natick, Mass., Tech Rpt ES-14, Dec 64.

[68] R.A. Hamilton and G. Rollitt, "British North Greenland Expedition 1952-54; climatological tables for the site of the expedition's base at Britannia Sø (lake) and the station on the inland-ice Northice," København, C.A. Reitzels Forlag, Medd Grønland, Vol. 158, pp. 1-83, 1957.

lower than -66°C (-87°F) at other times.[69]

North America's lowest temperature (excluding Greenland)
-63°C (-81°F)
Snag, Yukon Territory, 3 February 1947

Snag Aerodrome, which was in operation from 1943 to 1966, was located near the Alaskan border of Canada's Yukon Territory, at 62°23'N.140°23'W., elevation 646 meters (2,120 feet). This part of Canada resembles the Verkhoyansk-Oimekon area of eastern Siberia in its continentality. At the time that the record low temperature was observed, the lowest gradation on the minimum thermometer that recorded it was -80°F, but a pencil mark was made at a distance about 4 degrees below -80°F.[70] However, subsequent laboratory calibration of the thermometer indicated an instrumental error of ±3 degrees; and a value of -63°C (-81.4°F) was officially set by the Canadian Meteorological Service.[71,72] On the preceding day, 2 February, the corrected minimum temperature was -80.1°F. Mayo, to the northeast of Snag, reached a low of -62°C (-80°F) on 3 February.[73] These records occurred during a prolonged cold spell caused by an influx of cold Arctic air accompanied by clear and calm weather.[74] Air pressure was high, the air was very dry, and the breathing of people and dogs caused a hissing sound and produced vapor trails and fog. The previous record Canadian low temperature was -61.1°C (-78°F) at Fort Vermilion, Alberta, on 11 January 1911.[75] A value of -61.3°C (-78.5°F) at Fort Good Hope, Northwest Territories, which

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[69] R.S. Quiroz, "Lowest Temperature in Greenland", Monthly Weather Rev, Vol. 86, No. 3, p. 99, Mar 58.

[70] A. Court and H.A. Salmela, "Improbable Weather Extremes and Measurement Needs", Amer Meteorol Soc Bull, Vol. 44, No. 9, pp. 571-75, Sep 63.

[71] Ibid.

[72] A. Thomson, "Lowest Temperature in Canada," Monthly Weather Rev, Vol. 86, No. 8, p. 298, Aug 58.

[73] M. Thomas, "-81°F. The Canadian Record Low", Weatherwise, Vol. 16, No. 6, pp. 270-71, Dec 63.

[74] H. Wexler, "A Note on the Record Low Temperature in the Yukon Territory, January-February 1947", Amer Meteorol Soc Bull, Vol. 29, No. 12, pp. 547-50, Dec 48.

[75] F.D. Manning, Climatic Extremes for Canada, op. cit.

was quoted in the 1970 and 1974 reports of weather extremes as Canada's lowest temperature prior to Snag's record has subsequently been considered erroneous by the Canadians and deleted from their records.[76]

On 7 January 1982, temperatures of -71°C (-96°F) and -69°C (-92°F) were reported from two weather stations that had been installed near Fort Nelson, in northeastern British Columbia, in connection with a permafrost study.[77] The temperature at Fort Nelson Airport was -42°C (-43.6°F). The extreme temperatures are attributed to intense cold air drainage in mountain valleys "produced by an intense cold arctic high-pressure cell which gave regionally still air and clear skies and permitted marked local cooling during the nights."[78] These records have not been accepted by Canada's Atmospheric Environment Service, and the -63°C (-81°F) at Snag is still officially North America's lowest temperature, other than Greenland. However, such values indicate that under appropriate topographic and atmospheric conditions, temperatures lower than the records shown for the Northern Hemisphere on the weather extremes maps can, and probably do, occur more often than might generally be supposed.

U.S. lowest temperature
-62°C (-80°F)
Prospect Creek, Alaska, 23 January 1971

This low temperature was recorded at a camp along the Alaskan pipeline in the Endicott Mountains southeast of Bettles at 66°48'N.150°40'W., 335 meters (1,100 feet) elevation. An official figure of -62.1°C (-79.8°F) was established "....after subsequent recalibration of the thermometer at the Bureau of Standards in Washington...."[79] It replaced t previous official United States low of -60°C (-76°F) recorded at Tanana, Alaska, in the Yukon Valley at 65°10'N.152°06'W., elevation 67 meters (220 feet) in

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[76] M. Thomas, op. cit.

[77] S.A Harris, "Cold Air Drainage West of Fort Nelson, British Columbia", Arctic, Vol. 35, No. 4, pp. 537-41, Dec 82.

[78] Ibid.

[79] Weatherwise, Vol. 24, No. 2, p. 94, Apr 71.

January 1886.[80] Among other low temperatures claimed for Alaska was one of -61°C (-78°F) recorded by an airways observer at Fort Yukon ($66^{\circ}34'$N. $145^{\circ}18'$W., elevation 127 meters or 417 feet) on 14 January 1934, two days after the weather station closed there, making the record unofficial.[81] Also, a minimum thermometer left at 4,572 meters (15,000 feet) on Mount McKinley for 19 years indicated a temperature lower than -73°C (-100°F) at some time during its exposure.[82]

Plateau Station, Antarctica, had
a mean temperature for a month of
-73°C (-100°F), July 1968, and
an annual mean temperature of
-57°C (-70°F), 1966 to 1969

Plateau Station is located at $79^{\circ}15'$S.$40^{\circ}30'$E., elevation 3,625 meters (11,890 feet). It is in or near the coldest part of the Antarctic, which is believed to be close to the ridge line in East Antarctica.[83] During the winter of 1968, there were 118 days with temperatures below -73°C (-100°F)[84] and on 20 July, the temperature dropped to -86.2°C (-123.1°F).[85] This is only 3 Celsius degrees (5.5 Fahrenheit degrees) above the world's record low temperature at Vostok. It is the lowest temperature recorded at a United States station. The July mean temperature for 1968 is believed to be

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[80] U.S. Environmental Science Services Administration, Temperature Extremes, op. cit.

[81] L.S. Seamon and G.S. Bartlett, op. cit.

[82] Ibid.

[83] H.H. Lamb, "Differences in the Meteorology of the Northern and Southern Polar Regions", Meteorol Mag, London, Vol. 87, No. 1038, p. 353-79, Dec 58.

[84] U.S. Army Natick Laboratories, "Annual Record of Major Events - FY 1969", Natick, Mass., 1969.

[85] United States Antarctic Research Program Calendar, 1985; produced in New Zealand for U.S. Navy Support Force Antarctica, 1984.

a new world record, $-73.2^{o}C$ ($-99.8^{o}F$).[86] It exceeds a mean of $-71.8^{o}C$ ($-97.2^{o}F$) during August 1958 at Sovietskaya,[87] a Russian station, at 78°24'S. 87°35'E., elevation 3,570 meters (11,713 feet). Sovietskaya reported an annual mean temperature of $-57.2^{o}C$ ($-71^{o}F$) during the IGY period in 1957 and 1958.[88] This is colder than Plateau Station's $-56.6^{o}C$ ($-70^{o}F$), but the area is not considered to be as cold. The periods of record at Plateau Station and Sovietskaya are not long enough, however, to be conclusive. Some other low average temperatures are $-55^{o}C$ ($-67^{o}F$) at Vostok during 1958 and 1959, and $-50.5^{o}C$ ($-59^{o}F$) at Amundsen-Scott Station (90°S, elevation 2,800 meters or 9,186 feet) for 1957-1964.[89] During this same period at Amundsen-Scott, the July temperature averaged $-59^{o}C$ (-74.5^{o}) with the maximums averaging $-56^{o}C$ ($-69^{o}F$) and the minimums, $-62^{o}C$ ($-80^{o}F$).[90]

c. Temperature Variations. Large differences in temperature can occur seasonally, diurnally, and in response to certain kinds of weather conditions. Areas in the interiors of continents, which are far from the moderating influences of oceans or other water bodies, can experience very warm temperatures in summer and very cold temperatures in winter. There is a great difference between their hottest and coldest temperatures of the year. Very extreme seasonal differences occur in Siberia, U.S.S.R. and in Canada's Yukon Territory. Diurnal temperature differences are greatest in areas where the air is dry and the sky is mostly clear so that the moderating influences of clouds and moist air are not present. Arid areas at high altitudes can have extreme variations in temperature, even between locations in the sun and shade. In parts of the Himalayas, for example, it is possible

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[86] P.C. Dalrymple, Geographic Sciences Laboratory, U.S. Army Engineer Topographic Laboratories, Fort Belvoir, VA., Personal Communication.

[87] J. Alt, "Quelques considérations générales sur la météorologie de l'Antarctique", La Météorologie, No. 57, pp. 17-42, 1960.

[88] N.A. Stepanova, op. cit.

[89] U.S. Environmental Science Services Administration, Temperature Extremes, op. cit.

[90] Ibid.

for a person to be too hot on the side of their body exposed to the sun and too cold on the other side.

Changes in wind direction in coastal areas, especially during times of the year when land-sea temperature differences are greatest, can cause rapid rises or falls in temperature. Such a change occurred in the Edinburgh, Scotland area in April 1969 when wind blowing in from cold water to the east was displaced by "...a vigorous gust of very noticeably warmer air from the southwest"[91]. The temperature rose about 12C° (21F°) in a short period of time.

Temperatures can fall quickly as a result of the advection of cold air masses and then drop even further from loss of heat through radiation. They can rise substantially in short periods of time as a result of foehns (warm, drying winds descending the lee sides of mountain ranges). Increases of 11 to 17 degrees Celsius (20 to 30 degrees Fahrenheit) in an hour are not uncommon along the eastern side of the Rocky Mountains in the United States and Canada.[92] Topographic influences can also contribute to extreme fluctuations in temperature.

U.S. largest 2-minute temperature rise
27C°, from -20 to 7 (49F°, from -4 to 45)
Spearfish, South Dakota, 22 January 1943

Rapid City, South Dakota, had three temperature rises
and two falls of 22C° (40F°) or more during a period
of 3 hours and 10 minutes, 22 January 1943

Spearfish is located at 44°30'N.104°W., elevation 1,108 meters (3,637 feet), and Rapid City is at 44°N.103°W., elevation 985 meters (3,234 feet).

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[91] I.H. Chuter, "A Sudden Rise of Temperature at Edinburgh", Weather, Vol. 21, No. 11, pp. 159-62, 1970.

[92] D.M. Ludlum, Weather Record Book, United States and Canada, Princeton, N.J., Weatherwise, 1971.

They are in the Black Hills, a dome-shaped mass culminating in peaks over 3,195 meters (7,200 feet) above sea level, which slopes abruptly on the east and gradually on the west. This region lies mostly between 43° and 45°N., and 103° and 104°30'W., and the effects of the topography on winds from the west cause rapid temperature changes to occur there rather frequently.

On 22 January 1943, very rapid and pronounced fluctuations in temperature took place in the Black Hills. The phenomenon, investigated by Hamann, was "...essentially the result of the wavering motion of a pronounced quasistationary front separating Continental Arctic air from Maritime Polar air...."[93] Local chinook[94] effects possibly contributed to the unusual conditions. At Spearfish, the temperature rose from -20°C (-4°F) at 7:30 a.m. to 7°C (45°F) at 7:32 a.m.[95] It dropped from 12°C (54°F) at 9:00 a.m. to -20°C (-4°F) at 9:27 a.m.[96]

At Rapid City, the temperature rose from -15°C (5°F) to 12°C (54°F) between 9:20 a.m. and 9:40 a.m., fell to -12°C (11°F) at 10:30 a.m., rose to 13°C (55°F) at 10:45 a.m., fell to -12°C (10°F) at 11:30 a.m., rose to 1°C (34°F) at 11:50 a.m., fell to -9°C (16°F) at 12:15 p.m., and rose to 13°C (56°F) at 12:40 p.m.[97]

Changes were so rapid that buildings were experiencing winter on one side and spring around the corner. The phenomenon also caused sharp contrasts between some nearby places. For example, at Lead, South Dakota, the temperature was 11°C (52°F), while at Deadwood, less than 4.8 kilometers (3

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[93] R.R. Hamann, "The Remarkable Temperature Fluctuations in the Black Hills Region, January 1943", Monthly Weather Rev, Vol. 71, No. 3, pp. 29-32, Mar 43.

[94] A name given to foehns in the Western United States and Canada.

[95] U.S. National Oceanic and Atmospheric Administration. Environmental Data and Information Service, *op. cit.*

[96] *Ibid.*

[97] R.R. Hamann, *op. cit.*

miles) away, it was -27°C (-16°F).[98]

In Canada, similar conditions have occurred. At Pincher Creek, Alberta, on 6 January 1966, the temperature rose 25 Centigrade degrees (45 Fahrenheit degrees) from -24°C to 0.5°C (12°F to 33°F) and fell 22 Centigrade degrees (40 Fahrenheit degrees) from 0.5°C to -22°C (33°F to 7°F) during a 2-hour period.[99] Several hours later it again rose 25.5 Centigrade degrees (46 Fahrenheit degrees) from -23°C to 2°C (-10°F to 35°F) within an hour.

C. PRECIPITATION. Precipitation is measured by the depth to which it covers a horizontal unit area during a given period. Precipitation is caught in gauges whose diameter represents the horizontal unit area. The more representative the catch is of actual fall over the entire observation area, the more useful the measurement. For this reason, site, form, and exposure of the gauge are important, and precautions must be taken to prevent precipitation from splashing out of the gauge or being blown out by wind. In hot, dry areas evaporation can be a problem. Various requirements to cover these points have been established by the World Meteorological Organization.[100]

Gauges are of two main kinds -- the ordinary, or nonrecording gauges, and recording gauges. The former provide a means of collecting and measuring precipitation, and the latter incorporate mechanisms for recording the amount of fall during a given period or the rate of fall at any instant. Descriptions of the many varieties of recording and nonrecording gauges can be found in Middleton and Spilhaus, Meteorological Instruments.[101]

Even with the most efficient instruments, functioning perfectly and in

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[98] *Ibid.*

[99] D.M. Ludlum, *op. cit.*

[100] World Meteorological Organization, *op. cit.*

[101] W.E.K. Middleton and A.F. Spilhaus, *Meteorol Instruments*, 3rd ed., Univ. of Toronto Press, Toronto, 1953.

the most favorable sites and exposures, there are still problems in obtaining representative precipitation values. The standard gauge diameter is 20 centimeters (8 inches) in the United States. Therefore, the horizontal unit area covered by the measured precipitation is about 322.5 square centimeters (50 square inches), and measuring sites are often several miles apart. Furthermore, intense rainfall is often very localized and may be missed by the observation network. An example of such a rainfall, which occurred at Island Falls, Maine, in August 1959, is described by Lautzenheiser and Fay.[102] An even more localized example, from the southern New Hampshire area, occurred in August 1966.[103] A very intense rainfall totalling approximately 14.6 centimeters (5.75 inches) was reported by a volunteer weather observer. Most of it fell during a 2 1/2 hour period, and it was measured in a V-type plastic gauge of 15-centimeter (6-inch) capacity. The next nearest gauge, 0.04 kilometers (0.3 miles) away, measured 1.27 centimeters (0.50 inches), and the greatest amount reported at any official weather station in New Hampshire was 4.47 centimeters (1.76 inches). This "excessive rain of amazingly small areal extent" could be attributed to the influence of various factors: association with the jet stream, which is conducive to localized precipitation; association with small waves that develop in the lee of mountains; and the superposition of a wind jet and cold front, which favors great instability and wave formations.[104]

a. Greatest Precipitation. There are three general types of precipitation; convective, cyclonic, and orographic. Each has its characteristics and geographical distributions as well as different expectations for record extremes. Convective rain results from overturning of cooler air by warmer air from below and takes the form of heavy, localized showers, such as thundershowers. Convective showers tend to be most frequent in warm areas

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[102] R.E. Lautzenheiser and R. Fay, "Heavy Rainfall at Island Falls, Maine, 28 Aug 59", Monthly Weather Rev, Vol. 94, No. 12, pp. 711-714, Dec 66.

[103] R.E. Lautzenheiser, A.E. Rothovius and J.E. Sims, "Weather Note: Remarkable Point Rainfall at Greenfield, N. H., Evening of August 2, 1966", Monthly Weather Rev, Vol. 98, No. 2, pp. 164-168, Feb 70.

[104] Ibid.

and seasons and are responsible for many of the extreme short-period rainfalls.

Cyclonic precipitation results from mechanisms associated with low-pressure centers (cyclones) and with zones of convergence of different air masses (fronts). The most severe cyclonic storms, hurricanes or typhoons, bring very heavy and prolonged rain and are responsible for most of the extreme amounts that occur over a period of several hours or days. Certain parts of the world, mostly oceanic and coastal areas, lie along the tracks usually taken by these storms. The storms are prevalent in different areas at different times of the year; their tracks are mapped by month in the U.S. Navy's Marine Climatic Atlas of the World.[105]

Orographic precipitation results from upward deflection of air when it strikes higher ground. This often occurs in conjunction with convective and cyclonic types and tends to increase the precipitation amounts produced by them. The increase is greatest on steep slopes. Precipitation can also increase when sharply narrowing valleys between slopes act as funnels on up-valley winds. Highlands in the path of moisture-carrying winds from warm seas have abundant and frequent precipitation; such areas have the highest average yearly rainfalls. Among them are the east- and south-facing slopes of the Himalayas, the western slopes of the Andes in Colombia, and mountain ranges along the northwest coast of North America. Annual mean precipitation values often differ slightly in different sources because of differences in the years and length of record. (This is also true of the average values for other meteorological elements.) The number of years of record for each of the precipitation means included on the weather extremes maps are given in table 1 and on the reverse sides of the maps. Generally, a longer period of record would be more reliable than a short one.

[105] H.L. Crutcher and O.M. Davis, U.S. Navy, Marine Climatic Atlas of the World, Vol. 8, The World, (NAVAIR 50-1C-54), U.S. Naval Weather Service Command, 1969.

World's greatest 1 minute rainfall
3.1 centimeters (1.23 inches)
Unionville, Maryland, 4 July 1956

The U. S. Weather Bureau's investigation of this record is described by H. H. Engelbrecht and G. N. Brancato.[106] The extreme fall occurred during an afternoon of intense thunderstorms in the foothills of northern Virginia and adjacent north-central Maryland. At Unionville, the total precipitation during the storm was 9.1 centimeters (3.60 inches), of which 7.2 centimeters (2.84 inches) fell during a 50-minute period from 2:50 to 3:40 p.m. Rainfall was measured with a recording rain gauge located in satisfactory exposure. Some 13 points pertaining to functioning of the gauge were considered in evaluating this record by Engelbrecht, then State Climatologist for Maryland, and T. E. Hostrander, who was Substation Inspector. An enlarged photograph of the recording rain gauge chart revealed that at chart time 3:23+ the pen was at 2.47 inches on the chart scale and at chart time 3:23- it was at 3.70 inches. It was concluded that "...1.23 inches of precipitation occurred in an estimated period of one-minute or less...."[107] This exceeded the previous world record 1-minute rainfall of 1.75 centimeters (.069 inch) at Jefferson, Iowa, which in turn had exceeded the earlier record of 1.65 centimeters (0.65 inch) at Opid's Camp, California.

World's greatest 42-minute rainfall
30.5 centimeters (12 inches)
Holt, Missouri, 22 June 1947

G. A. Lott has examined the meteorological data available for this

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[106] H.H. Engelbrecht, and G.N. Brancato, "World Record One-Minute Rainfall at Unionville, Maryland", Monthly Weather Rev, Vol. 87, No. 8, pp. 303-306, Aug 59.

[107] Ibid.

storm and considered the factors responsible for its remarkable intensity.[108] According to him, the storm occurred "...as a local intensification in a long, narrow, warm sector convective system (the leading edge of which may be interpreted as an instability line) a short distance ahead of a surface cold front...." He further states that "... a unique factor was the tightening of the pressure gradient north of an instability-line Low, causing an extraordinarily strong low-level flow of unstable air into the pre-existing convective system...." The storm was reported by seven volunteer observers, two of whom noted the 12-inch occurrence in 42 minutes.[109] Many roads and bridges were washed out in the area surrounding the small Missouri town.

The world's greatest precipitation in 60 minutes is listed by R. J. Schmidli as occurring both at Holt, Missouri, and at Kilauea Sugar Plantation, Kauai, Hawaii.[110] The amount, 30.5 centimeters (12 inches), is the same for both places. The rainfall at Kilauea occurred during the storm on 24 and 25 January 1956 in which over 96.5 centimeters (38 inches) fell within a 24-hour period, 15 centimeters (6 inches) during a 30-minute period, and about 30.5 centimeters (12 inches) in 1 hour.[111] "The 38-inch value for 24 hours is conservatively low, because the gage was already overflowing when it was emptied for the first time. The six-inch value is correct within one or two tenths of an inch; the 12-inch value for one hour is an estimate only--again because of overflow--and may be in error by as much as an inch."

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[108] G.A. Lott, "The World-record 42-minute Holt, Missouri, Rainstorm", Monthly Weather Rev, Vol. 82, No. 2, pp. 50-59, Feb 54.

[109] U.S. Weather Bureau, Hydrologic Bulletin Daily and Hourly Precipitation, Missouri River District, Jun 47.

[110] R.J. Schmidli, Weather Extremes (Revised), Salt Lake City, Utah, U.S. National Oceanic and Atmospheric Administration, National Weather Service, Western Region (NOAA Technical Memorandum NWS WR-28), Dec 83.

[111] U.S. National Oceanic and Atmospheric Administration, Environmental Data Service, Climatography of the United States, #60, Climate of Hawaii, Asheville, N.C., National Climatic Center, Jul 78.

World's greatest 12-hour rainfall

135 centimeters (53 inches)

Belouve, La Réunion Island, 28-29 February 1964

World's greatest 24-hour rainfall

188 centimeters (74 inches)

Cilaos, La Réunion Island, 15-16 March 1952

World's greatest 5-day rainfall

386 centimeters (152 inches)

Cilaos, La Réunion Island, 13-18 March 1952

La Réunion Island is located in the Indian Ocean east of Madagascar, at approximately 21°S.55°30'E. It is about 48 by 64 kilometers (30 by 40 miles) in extent and very mountainous, with steep slopes up to 3,300 meters (10,000 feet) and narrow valleys where winds are funnelled to increase the orographic effects. Sea surface temperature is highest during the tropical cyclone season, reaching 27°C (81°F) in March.[112]

The record-producing rainfall at Cilaos occurred during a tropical cyclone as did, presumably, that at Belouve. Another very heavy rainfall of 158 centimeters (62.33 inches) in 1 day and 345.5 centimeters (136.83 inches) in 5 days, occurred at Aurere on La Réunion in April 1958. All three of these storms broke the previous 24-hour world record, 117 centimeters (45.99 inches) at Baguio in the Philippines in 1911; and the Cilaos storm broke the previous record of 381 centimeters (150 inches) at Cherrapunji, India, in August 1841. The values given for Aurere and Cilaos were obtained from a survey of about 6 years of official published data for those places, and the February 1964 rainfall at Belouve was reported in a communication from the French Meteorological Service.[113] Since these record-breaking amounts

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[112] J.L.H. Paulhus, "Indian Ocean and Taiwan Rainfall Set New Records", Monthly Weather Rev, Vol. 93, No. 5, pp. 331-35, May 65.

[113] Ibid.

"...were the result of an incomplete survey of a short period of record, there is a good chance that a more thorough survey of a longer period of record would disclose other, and perhaps even greater, amounts of similar magnitude..."[114]

These rainfall amounts from La Réunion not only broke the previous records for the time periods during which they occurred, they also surpassed some of the estimates of the greatest amounts that could occur. Formulas to compute the greatest amounts possible for various durations have been developed by J. L. H. Paulhus, on the basis of the La Réunion records, and by S. Marx.[115,116] According to the formula of Paulhus, the greatest amount for 12 hours would be 137 centimeters (54 inches); for 24 hours, 191 centimeters (75 inches); and for 1 hour, 42 centimeters (16.6 inches).[117] According to Marx's formula, the greatest amount for 12 hours would be 135.5 centimeters (53 inches) and for 1 hour, 39 centimeters (15 inches).[118]

Northern Hemisphere's greatest 24-hour rainfall
125 centimeters (49 inches)
Paishih, Taiwan, 10-11 September 1963

Paishih is located at 24°33'N.121°13'E., at 1,636 meters (5,368 feet) on the island of Taiwan. Taiwan, like La Réunion, is very mountainous and is surrounded by warm ocean water, 28°C (82°F) in August and September during the tropical cyclone season. The record rainfall, 124.79 centimeters (49.13 inches), occurred during Typhoon Gloria, and it was measured in a recording

[114] Ibid.

[115] Ibid.

[116] S. Marx, "Über die extremsten Niederschlagsmengen auf der Erde" [About the Most Extreme Rainfall Amounts of the Earth], Zeitschrift für Meteorol, Vol. 21, No. 3-4, pp. 118-19, 1969.

[117] Ibid.

[118] Ibid.

gauge, thus adding to the reliability of the observation.[119] Rain of similar intensity fell at nearby stations during the same storm. At one of these places, Paling, total rainfall during the typhoon was greater than at Paishih, and for some durations intensity might have been greater. However, no further information on Paling is available.

Alvin, Texas, had a 24-hour rainfall of
109 centimeters (43 inches)
25-26 July 1979

Alvin is located on the flat coastal plain about 25 miles south of Houston at approximately 29°25'N.91°15'W. The extreme rainfall there occurred in connection with tropical storm Claudette. When this storm moved into southeastern Texas, weak stirring currents allowed it "to drift for about 30 hours in a region of very high residual moisture while its circulation continued to bring large amounts of moisture onshore from the nearby Gulf".[120] The 109 centimeters (43 inches) of rainfall was measured between noon on 25 July and noon on 26 July, and 66 centimeters (26 inches) fell in the 10-hour period between 9 p.m. and 7 a.m.[121] Although this is not an official record, it is one of the "few well-accepted unofficial extremes" included by Schmidli,[122] as was the previous 24-hour record of 99 centimeters (39 inches) for North America at Yankeetown, Florida. It exceeds the 99 centimeters (39 inches) at Dharampuri, India, which has been included on the 1970 and 1974 maps of weather extremes as "possibly the world's greatest on flat terrain."

Australia's greatest 24-hour rainfall
91 centimeters (36 inches)
Crohamhurst, Queensland, 3 February 1893

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[119] J.L.H. Paulhus, _op. cit._

[120] J.D. Hill, "An Apparent New Record for Extreme Rainfall", _Weatherwise_, Vol. 33, No. 4. pp. 157-61, Aug 80.

[121] _Ibid._

[122] R.J. Schmidli, _op. cit._

This record, discussed by Newman, is officially accepted and apparently quite reliable.[123] It occurred during a cyclonic storm in which comparable heavy rain fell at nearby stations. However, on 4 January 1979, it was exceeded by a rainfall of 114 centimeters (44 inches) at Bellenden Ker, Queensland.[124] The new record has been officially accepted by the Australian Bureau of Meteorology, but word of it was received too late for inclusion on the world weather extremes map.

U.S. greatest 12-month rainfall
1878 centimeters (739 inches)
Kukui, Maui, Hawaii,
December 1981 to December 1982

Kukui is located in a mountainous area at an ele ·tion of 1,764 meters (5,788 feet) at 20°54'N.156°36'W. on the island of Maui.[125] The rainfall there in 1981-1982 surpassed the previous United States record for 12 months, 1,585 centimeters (624 inches), at Mount Waialeale, Hawaii, between 24 July 1947 and 27 July 1948.[126] Kukui also had the greatest precipitation in the United States during a calendar year, 1,790 centimeters (704.83 inches) in 1982.

World's greatest average yearly precipitation
1,168 centimeters (460 inches)
Mount Waialeale, Kauai, Hawaii

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[123] B.W. Newman, "Australia's Highest Daily Rainfall", Australian Meteorol Mag, No. 20, pp. 61-65, Mar 58.

[124] J. de la Lande, Australia. Bureau of Meteorology, Victorian Regional Office, Melbourne, Victoria, correspondence dated 5 Jul 85.

[125] U.S. Weather Bureau, Substation History, Hawaii and Pacific Ocean Area, (Key to Meteorological Records Documentation No. 1.1), Washington, D.C., GPO, 1958.

[126] R.J. Schmidli, op. cit.

The value of 1,168 centimeters (460 inches) is based on data for the period from 1931 through 1960.[127] Higher averages are cited for other periods of record, e. g. 1,199 centimeters (472 inches) for 1912 through 1949[128] and 1,234 centimeters (486 inches) for a more recent period beginning (presumably) in 1941.[129] Mount Waialeale is located on the island of Kauai, at 22°04'N.159°30'W. Conditions pertinent to the record rainfall are described by Henning.[130] According to him, the storage rain gauge is at an elevation of 1,547 meters (5,075.5 feet), and measurements are made at 3-month intervals.

Asia's greatest average yearly precipitation
1,143 centimeters (450 inches)
Cherrapunji, India

When the summer monsoon depressions (moderately vigorous, warm-cored cyclonic disturbances accompanied by heavy rain) from the Bay of Bengal reach the Himalayas, the rainfall is further increased by orographic lifting.[131] As a result of these monsoon disturbances, which are still not fully understood, the eastern Himalayan foothills are very wet regions. Cherrapunji is located in this area at 25°02'N.91°08'E., 1,313 meters (4,309 feet) in elevation. The annual precipitation record there is based on a

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[127] U.S. Environmental Science Services Administration, Environmental Data Service, Local Climatological Data; annual summary with comparative data, 1967, Lihue, Hawaii, Washington, D.C., GPO, 1968.

[128] L.H. Seamon and G.S. Bartlett, op. cit.

[129] U.S. National Oceanic and Atmospheric Administration, Environmental Data Service, Climatography of the United States, #60, Climate of Hawaii, op. cit.

[130] D. Henning, "Mt. Waialeale", Wetter und Leben, Vienna, Vol. 19, No. 5/6, pp. 93-100, 1967.

[131] J.M. Walker, "The Monsoon of Southern Asia: A Review", Weather, Vol. 27, No. 5, pp. 178-89, 1972.

74-year period.[132] In addition to the Asian record for annual mean precipitation, Cherrapunji also holds records for the world's greatest rainfalls for various durations of from 15 days to 2 years.[133] Among these are the greatest rainfalls in 1 month, 930 centimeters (366 inches) in July 1861, and in 12 months, 2,647 centimeters (1,042 inches) from August 1860 to July 1861. The greatest amount for a calendar year at Cherrapunji is 2,298.95 centimeters (905.1 inches) and the least, 717.8 centimeters (282.6 inches).[134] Another place in this Himalayan region, Mawsynram, Assam, could be a rival to Cherrapunji.[135]

South America's greatest average yearly precipitation
899 centimeters (354 inches)
Quibdó, Colombia

Quibdó is situated at an elevation of 37 meters (120 feet) at $5^{\circ}41'N.76^{\circ}40'W$. A rainfall average of 1,049 centimeters (413 inches) at Quibdó, based on data from 1931 through 1946 taken from Colombian sources,[136,137] was cited on the 1964 revision of the world weather extremes map. Earlier maps cited a value of 869 centimeters (342 inches) at Buena Vista,

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[132] U.S. Environmental Science Services Administration, Worldwide Extremes of Temperature, Precipitation and Pressure Recorded by Continental Area, op. cit.

[133] J.L.H. Paulhus, op. cit.

[134] U.S. Environmental Science Services Administration, Worldwide Extremes of Temperature, Precipitation and Pressure Recorded by Continental Area, op. cit.

[135] A.M. Riabchikov, "Cherrapundzhi ili Mausinram-samoe dozhdlivoe mesto na Zemle?" [Cherrapunji or Mawsynram--Which is the Rainiest Spot on Earth?] Moscow, Universitet, Vestnik, Ser 5, Geografiia, Vol. 25, No. 3, pp. 79-81, 1970.

[136] Colombia, Bol Agri, between 1929 and 1947.

[137] Colombia. Departmento de Irragación, Sección de Meteorológico y Afros, Anuar Meteorol, 1934-1947.

Colombia.[138] The value of 354 inches shown on the current map was obtained from Environmental Data Service.[139]

North America's greatest average yearly precipitation
650 centimeters (256 inches)
Henderson Lake, British Columbia

This station was at a fish hatchery, now closed, at the head of Henderson Lake on the west coast of Vancouver Island at 49°08'N.125°08'W., elevation 4 meters (12 feet). The topography there contributes to extreme rainfall through orographic lifting reinforced by convergence.[140] Mountains to the north and northwest of the station are at right angles to the main inflows of moist air. A direct onshore flow of moist air may be deflected by the mountains and converge in the Henderson Lake area. During these conditions, it is also likely that the outflow in the lowest level from Juan de Fuca Strait adds to the convergence. A nearby station, Ucluelet Brynnor Mines, had the greatest 1-day precipitation in Canada, 48.92 centimeters (19.26 inches).[141] Henderson Lake had the second greatest 1-day amount, 42.19 centimeters (16.61 inches), as well as Canada's greatest annual precipitation, 812.24 centimeters (319.78 inches), which occurred in 1931.[142] The greatest amount in a calendar year in North America, 831 centimeters (332.29 inches), occurred at MacLeod Harbor, Alaska, in 1976.[143]

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[138] L.H. Seamon and G.S. Bartlett, op. cit.

[139] M.A. Arkin, Chief, Foreign Branch, Environmental Data Service, U.S. Environmental Science Services Administration, correspondence dated 6 Oct 69.

[140] J.G. Potter, Record Precipitation on One Day in Canada, Canada. Meteorological Branch, Toronto, CDC #1-68, 1968.

[141] Ibid.

[142] F.D. Manning, Climatic Extremes for Canada, Canada. Atmospheric Environment Service, Downsview, Ontario (CLI-383), 1983.

[143] R.J. Schmidli, op. cit.

Australia's greatest average yearly precipitation
455 centimeters (179 inches)
Tully, Queensland

This value was obtained over a 39-year period of record[144] and is shown on the current world weather extremes map. According to information received from the Australian Bureau of Meteorology in July 1985, Tully's average yearly precipitation during a longer (59-year) period of record was 425 centimeters (167 inches).[145]

b. Least Precipitation. Generally, areas of low precipitation occur in continental interiors, on lee sides of high mountains, on coasts adjacent to cool currents, in zones of higher atmospheric pressure where the air is subsiding, and in high latitudes. Arid areas are found in east Africa and adjacent southwest Asia between 15° and 35°N, western South America between 5° and 30°S, eastern South America between 35° and 50°S, western Africa between 15° and 35°S, western and interior Australia, interior Asia, parts of western North America between 25° and 40°N, and in the polar regions. As with records of high average precipitation, those of low average precipitation vary according to the years on which they are based, and they tend to be more reliable for a longer period. In some very dry areas, e.g. Chile and Sudan, several years can pass with no precipitation.

c. Precipitation Variability. Variations in precipitation can be upward, i.e. occurrence of above-average amounts; or downward, i.e. occurrence of below-average amounts or even drought. Among the factors causing variations are displacements of ocean currents and differences in strength of the monsoonal circulation from year to year. Coasts adjacent to cold currents are generally dry, but if the current deviates even slightly, making room for warmer water, relatively abundant rainfall can occur, as in

[144] U.S. Environmental Science Services Administration, Environmental Data Service, Worldwide Extremes of Temperature, Precipitation and Pressure Recorded by Continental Area, op. cit.

[145] J. de la Lande, op. cit.

the coastal areas of Chile and Peru. Disastrous droughts in northeast Brazil might be due to the opposite occurrence, invasion of warmer water by cold currents. The other factor, differences in strength of monsoonal circulations, is most pronounced along the borders of areas covered by these seasonal winds. During years of weak monsoon, less territory is covered by the rain-bearing winds and less rain is deposited by them.

Debundscha, Cameroon, has
191 centimeters (75 inches)
average variability of annual precipitation

The average and relative variability of annual precipitation at 384 places throughout the world were tabulated by E. Biel[146] and examined statistically by V. Conrad.[147] Places with greatest average variability (the average of the differences between mean value and individual yearly value for a given number of years) were Debundscha, Cameroon, and Cherrapunji, India, with 191 and 168 centimeters (75.28 and 66.02 inches), respectively. Debundscha is located at 4°01'N.9°01'E. at 9 meters (30 feet) elevation and has the greatest average yearly precipitation in Africa, 1,029 centimeters (405 inches). Cherrapunji has the greatest average yearly precipitation in Asia, 1,143 centimeters (450 inches).[148] Because the rainfall amounts at these places are so high, the average differences from year to year can be correspondingly high without being extreme in proportion to the mean. In addition to having a very high average variability of annual precipitation, Cherrapunji may hold the record for the highest actual amount of variability. The difference between the greatest amount of precipitation there during a calendar year, 2,298.95 centimeters (905.1 inches), and the

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[146] E. Biel, "Die Veranderlichkeit der Jahressumme des Niederschlags auf der Erde" [The Variability of the Yearly Amount of Precipitation of the Earth], Geograph J aus Oesterreich, Leipzig, Vols. 11-15, pp. 151-80, 1929.

[147] V. Conrad, "The Variability of Precipitation", Monthly Weather Rev, Vol. 69, No. 1, pp. 5-11, Jan 41.

[148] U.S Environmental Science Services Administration, Worldwide Extremes of Temperature, Precipitation and Pressure Recorded by Continental Area, op. cit.

least amount, 717.8 centimeters (282.6 inches), is over 1,581 centimeters (600 inches).[149]

Themed, Israel, has a
94 percent
relative variability of annual precipitation

Themed is a desert station on the Sinai Peninsula. Its relative variability record is based on the ratio of the mean deviation from the arithmetic mean of annual precipitation for a period of years beginning in 1921 and ending in 1947 divided by the arithmetic mean for those years.[150] Other places with high values based on this same measure of variability are Walvis Bay, at 22°53'S.14°26'E. in Southwest Africa with 87 percent,[151] and Malden Island in the Line Islands of the equatorial Pacific with 71 percent.[152] Walvis Bay, like Themed, is a very dry area, and because the rainfall amounts at these places are so low, a small variation in actual amount can become a large percentage of the mean value. Malden Island's average variability of 51.41 centimeters (20.24 inches) from its mean annual precipitation of 72.6 centimeters (28.6 inches) is thought to be due to displacement of ocean currents.[153]

The relative variability of monthly rainfall can have even higher values than that of annual rainfall. A value of 193 percent for September has been cited at Beersheba, Israel (31°14'N.34°47'E.), where rain fell in

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[149] Ibid.

[150] J. Katsnelson and S. Kotz, "On the Upper Limits of Some Measures of Variability", Archiv für Meteorol, Geophysik und Bioklimatol, Ser. B, Vol. 8, No. 1, pp. 103-107, 1957.

[151] Ibid.

[152] E. Biel, op. cit.

[153] Ibid.

only 1 of 30 Septembers from 1921 through 1950.[154] This almost reaches the theoretical upper limit of 200 percent determined analytically by Schumann and Mostert.[155]

Lhasa, Tibet, had a
108 percent
relative variability
of annual precipitation, 1935 to 1939

Lhasa is located on the Tibetan plateau at 29°40'N.91°07'E., elevation 3,685 meters (12,090 feet). It is in an approximately east-west valley flanked on both sides by mountains of 4,572 to 4,877 meters (15,000 to 16,000 feet). Its climate has been described by Ginn-Tze Hsü, who established a meteorological station there in 1934,[156] and also by A. Lu[157] and H. Flohn.[158] Data for 1935 through 1938 from Lu's paper[159] were calculated by Conrad's methods[160] to obtain the average variability of 171.9 centimeters (67.7 inches) and a relative variability of 108 percent.

In 1936, the annual precipitation reported for Lhasa, 503.7 centimeters (198.3 inches), was more than 10 times greater than the average amount. However, there is some doubt as to the authenticity of the amount of precipitation recorded for 1936. Flohn considers the value questionable and

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[154] J. Katsnelson and S. Kotz, op. cit.

[155] T.E. Schumann and J.S. Mostert, "On the Variability and Reliability of Precipitation", Amer Meteorol Soc Bull, Vol. 30, No. 110, 1949.

[156] Ginn-Tze Hsü, "A Note on the Climatic Conditions of Lhasa", Amer Meteorol Soc Bull, Vol. 22, No. 2, pp. 68-70, Feb 41.

[157] A. Lu, "A Brief Survey of the Climate of Lhasa", Quarterly J Roy Meteorol Soc Bull, Vol. 65, No. 281, pp. 297-302, Jul 39.

[158] H. Flohn, "Beitrage zur Klimak unde von Hochasien" [Contributions Towards a Climatology of the Central Asian Plateau], Erdkunde, Vol. 12, No. 4, pp. 294-308, Dec 58.

[159] A. Lu, op. cit.

[160] V. Conrad, op. cit.

attributes it to a possible misplacement of a decimal point by a partly educated weather observer.[161] On the basis of Lu's data and for most of the years from 1941 to 1955, Flohn found no amount that even approached that of 1936. The highest was 58.1 centimeters (22.9 inches). The frequency of precipitation, as indicated by the number of rainy days during 1936, was not unusual. Furthermore, Gyantse, in the same climatic region as Lhasa at 28°56'N.89°36'E., elevation 3,196 meters (10,486 feet), had no similar extreme variation in a 38-year period. In 1936, Gyantse had only 33 centimeters (13 inches) more than the average precipitation.

However, Hsü was at Lhasa in 1936, presumably as the station observer or supervisor, and he wrote about the unusually heavy rain and its causes[162] and informed Lu[163] of the difference between the rainfall in 1936 and in other years. Normally, rainfall at Lhasa comes from thundershowers, but in 1936 only 23 percent was of this type and 69 percent was from nighttime rain, possibly caused by interaction between a strong southwest monsoon and cold air masses from the north.[164] In another paper, Lu described a similar extreme variation at Omei Shan, China, to the east of Lhasa, at approximately 29°30'N.103°30'E., elevation 3,055 meters (10,023 feet).[165] The annual mean there is 185 centimeters (73 inches), but during the Second Polar Year from August 1932 to August 1933, Omei Shan had 810 centimeters (319 inches), "...the largest amount ever recorded in China in a 13-month period...."[166] This difference of 625 centimeters (246 inches) between the annual mean and the August 1932 to August 1933 value is even greater than the difference between Lhasa's annual mean and its 1936 precipitation. Flohn's paper also mentioned Omei Shan, but his figures differ somewhat from Lu's with a

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161 H. Flohn, _op. cit._

162 Ginn-Tze Hsü, _op. cit._

163 A. Lu, _op. cit._

164 _Ibid._

165 A. Lu, "Precipitation in Tibet", _Geograph Rev_, Vol. 37, No. 1, pp. 88-93, Jan 47.

166 _Ibid._

63.5-centimeter (25-inch) annual mean and 762 centimeters (300 inches) in the Second Polar Year, making a difference of 698.5 centimeters (275 inches).[167]

d. Hail. The different characteristics of hail (e.g. frequency, intensity, season of occurrence, hailstone size) vary with latitude and location in regard to landforms, water bodies, and urban areas. Generally, hail occurs most often in the interiors of continents at middle latitudes. In North America, the principal hail area is "along and to the lee of the eastern Rocky Mountains and from New Mexico to Alberta. This area averages more hail days, more hailstorms, more and bigger hailstones, and thus a greater hail intensity than any other area in the continent."[168]

U.S. largest hailstone
44.5 centimeters (17.5 inches) circumference
Coffeyville, Kansas, 3 September 1970

Hailstones are pieces of ice that precipitate either separately as spheres or cones, or agglomerated into irregular lumps. They originate in convective clouds of the cumulonimbus type and are usually associated with thunderstorms. The hailstone at Coffeyville, 37°02'N.95°37'W., is the largest officially recorded in the United States, and according to a British publication, it is "the world's heaviest fully authenticated hailstone".[169] It weighed 758 grams (1.67 pounds)[170] and measured about 14 centimeters (5.6 inches) in diameter.[171] It fell during a severe storm with hundreds of other

[167] H. Flohn, op. cit.

[168] S.A. Changnon, Jr., "The Scales of Hail", J Applied Meteorol, Vol. 16, No. 6, pp. 626-48, Jun 77.

[169] G.T. Meaden, "Giant Ice Meteor Mystery", J Meteorol, Trowbridge, England, Vol. 2, No. 17, pp. 137-41, Mar 77.

[170] "The New Champ Hailstone", Weatherwise, Vol. 24, No. 4, p. 151, 1971.

[171] I.I. Gringorten, Hailstone Extremes for Design, Air Force Surveys in Geophysics, No. 238, U.S. Air Force Cambridge Research Laboratories, Bedford, Mass., AFCRL-72-0081, Dec 71.

large stones in southeast Kansas and was preserved and sent to the National Center for Atmospheric Research where it was photographed. The photograph shows that it was irregular in shape and had five alternating layers made up of either clear or milky-appearing ice. The previous official hailstone record in the United States, which appeared on earlier maps of weather extremes, was for a hailstone that weighed 680 grams (1.5 pounds) and measured 43 centimeters (17 inches) in circumference. It was recorded at Potter, Nebraska, on 6 July 1928.

Canada's heaviest hailstone
290 grams (10.23 ounces)
Cedoux, Saskatchewan, 27 August 1973

This record is discussed by L. Wojtiw and E. P. Lozowski.[172] According to them, the man who picked it up stated that the stone had spiky lobes and "a half inch of ice melted in his hands during the half hour required to get it to a freezer." From this information, the authors estimate that "its mass on falling could therefore have been as high as 450 gm." It fell during a series of storms in southeastern Saskatchewan that were accompanied by "a great deal of larger than golfball hail and high winds." It measured 10.2 centimeters (4 inches) in diameter; but hailstones as large as or larger than that have fallen in Canada.[173] Among these is one with a diameter of 12.7 centimeters (5 inches) that fell at Windigo Lake, Ontario, on August 23, 1948. This record, however, has not been verified.

Outside of the United States and Canada, less information is available about hail and hailstones. However, claims have been made of large hailstones in many places. One hailstone weighing 972 grams (2.14 pounds) was picked up and photographed in Strasbourg, France, near the German border on 11 August 1958, and a heavier one of 1.9 kilograms (4.18 pounds) was picked

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[172] L. Wojtiw and E.P. Lozowski, "Record Canadian Hailstones", Amer Meteorol Soc Bull, Vol 56, No. 12, pp. 1275-76, Dec 75.

[173] M. Newark, "Canadian Weather Extremes", Chinook, Vol. 6, No. 3, pp. 76-78, Summer 84.

up in Kazakhstan, U.S.S.R., in 1959.[174] Among other areas where very large and heavy hailstones occur are Hungary,[175,176] China, and northern India.[177] In this last area, a very high frequency of large hailstones occurs as a result of the very tall thunderstorms that develop in the pre-monsoon squall lines.[178] "Sizes of hailstones appear to be largely dependent on the vertical extent (depth) of the storm, the amount of shear and/or the distance between cloud base and the surface (amount of evaporation and melting)."[179] Large hailstones and intense falls of hail are said to have killed people and animals and destroyed villages.[180,181]

e. Snow. There are two main ways of measuring snowfall depth: by direct measurement of fresh snow on open ground with a graduated ruler or scale and by a snow gauge. Precautions must be taken against drifting or blowing snow, or if the open ground method is used, against measurement of old snow. When there are strong winds, the snow gauge is more likely to be accurate. Greatest amounts of snowfall--as of rainfall--occur in areas where there is moist air and a mechanism for lifting it. Such areas are located in the middle latitudes rather than at the very high latitudes where there is less moisture.

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[174] J.P. Verdou, "Extrêmes climatiques mondiales" [World Climatic Extremes], France. Météorologie Nationale, Paris, MET-MAR Bull, No. 76, Jul 72.

[175] K. Bognar, "Reminiscences", Amer Meteorol Soc Bull, Vol. 52, No. 11, pp. 1102-03, 1971.

[176] A. Réthly, Weather Phenomena and Havoc Wrought by Weather between 1700-1800 in Hungary, Hungarian Academy of Sciences, Budapest, 1971.

[177] F.H. Ludlam, "The Hailstorm", Weather, Vol. 16, No. 5, pp. 152-62, 1961.

[178] S.A. Changnon, Jr., "Notes on Hailstone Size Distributions", J Applied Meteorol, Vol. 10, pp. 168-70, Feb 71.

[179] Ibid.

[180] D.M. Ludlum, op. cit.

[181] J.H. Field, "The Meteorology of India", J Roy Soc Arts, Vol. 82, pp. 784-806, 1933-34.

North America's greatest 24-hour snowfall

192.5 centimeters (76 inches)

Silver Lake, Colorado, 14-15 April 1921

Silver Lake is located at approximately 40°N.105°40'W., at 3,115 meters (10,220 feet) elevation in the Colorado Rockies. The snowfall there in April 1921 established several records: 192.5 centimeters (75.8 inches) in 24 hours, prorated from a measured fall of 221 centimeters (87 inches) in 27.5 hours; 241 centimeters (95 inches) in 32.5 hours; 249 centimeters (98 inches) in 72 hours; and 254 centimeters (100 inches) in 85 hours.[182] According to Paulhus, the measurement was examined thoroughly before being accepted by the U.S. Weather Bureau.[183] "...There was no evidence to indicate that the measurement was any less reliable than that of other heavy snowfalls, and it appears that a snowfall of this magnitude is meteorologically possible...." The maximum amount of snow that can fall in 24 hours has been estimated as approximately 183 centimeters (72 inches) for snow with a density of 0.10 under normal packing conditions and correspondingly greater for lesser density.[184] The density of the snow at Silver Lake was 0.06.[185] During the storm, thunder occurred in various parts of the region, indicating widespread convective activity, and the combined convective and orographic influences produced excessive amounts of snow at several places. In addition to the record at Silver Lake, a fall of 157.5 centimeters (62 inches) in 22 hours was reported at Fry's Ranch, Colorado. Both of these exceeded the previous U.S. record of 152 centimeters (60 inches) in 24 hours at Giant

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[182] J.L.H. Paulhus, "Record Snowfall of April 14-15, 1921, at Silver Lake, Colorado", Monthly Weather Rev, Vol. 81, No. 2, pp. 38-40, Feb 53.

[183] Ibid.

[184] C.F. Brooks, "On Maximum Snowfalls", Amer Meteorol Soc Bull, Vol. 19, No. 2, p. 87, Feb 38.

[185] J.L.H. Paulhus, "Record Snowfall of April 14-15, 1921 at Silver Lake, Colorado", op. cit.

Forest, California, in January 1933.[186]

Alaska's greatest snowfall in

24 hours, 157.5 centimeters (62 inches), 29 December 1955

one storm, 445.5 centimeters (175 inches), 26-31 December 1955

one season, 2,475 centimeters (974.5 inches), 1952-1953

Thompson Pass

This station is in south-central Alaska, at 61°07'N.145°44'W., elevation 823 meters (2,700 feet). It ranks near the top (second) among places holding North American records for the greatest amounts of snowfall in 24 hours, during a single storm, and during a season. Besides this, Thompson Pass has extremely frequent occurrences of these intense snowstorms. During the 20 winters from 1951-52 through 1970-71, there were 32 snowfalls of 76 centimeters (30 inches) or more during a 24-hour observation period reported at this station, and 13 of these snowfalls were at least 102 centimeters (40 inches).[187]

Bessans, France, had a snowfall of

172 centimeters (68 inches) in 19 hours

5-6 April 1959

Bessans is located at 1,710 meters (5,610) in the French Alps near the Italian border. Very intense snowstorms occur in this area as the result of a southeast wind, known locally as "la lombarde." These storms, of which the one at Bessans is a good example, are also very localozed. The meteorological and environmental conditions contributing toward them are examined by

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[186] Ibid.

[187] Climatological Data, Monthly, Alaska, U.S. Weather Bureau, 1951-65; U.S. Environmental Data Services, 1965-71; Asheville, N.C., 1966, 1972.

M. Jail.[188] Parts of Norway also have very high 24-hour snowfalls, as do parts of northwestern Japan and some other world areas. In this connection it should be mentioned that the predominance of North American records on the world weather extremes map is due to their availability rather than to greater amounts of snowfall on this continent.

D. OTHER EXTREMES. Besides temperature and precipitation, several other meteorological and climatic conditions are shown on the maps. For each of these, the most extreme occurrences have their own particular set of causes, limits, and distributions in time and space; and for each there are problems in obtaining accurate measurements. In evaluating reliability of the records, all of these factors should be taken into consideration.

a. Thunderstorms. A thunderstorm is a local storm defined as "... One or more sudden electrical discharges, manifested by a flash of light (lightning) and a sharp or rumbling sound (thunder). Thunderstorms are associated with convective clouds and are most often accompanied by precipitation which, when it reaches the ground, is in the form of a shower of rain, snow, snow pellets, ice pellets or hail."[189] They seldom last more than 2 hours. Criteria for recording thunderstorms can vary from storms actually occurring at a station to merely thunder heard or lightning seen from the station.

Thunderstorms are most prevalent in warm weather and, in some places, during the rainy season. However, although thunderstorms frequently produce heavy rainfall, there are places where seasons of rainfall and thunderstorm maxima do not coincide. In addition, some very rainy places have few thunderstorms, while places with very frequent thunderstorms can have

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[188] M. Jail, "Remarquable effet de lombarde: les chutes de neige de Paques 1969 en Haute-Maurienne", Revue de Géographie Alpine, Grenoble, Vol. 57, No. 3, pp. 613-21, 1969.

[189] World Meteorological Organization, International Cloud Atlas, Vol. 1, Manual on the Observation of Clouds and Other Meteors, (Partly Annex 1 to WMO Technical Regulations), revised edition, Secretariat of the World Meteorological Organization, Geneva, Switzerland, WMO No. 407, 1975.

relatively small amounts of rainfall.[190] Also, there are some places, e.g. in polar regions, where thunderstorms rarely occur.

Kampala, Uganda, averages
242 thunderstorm days per year

Kampala is located to the north of Lake Victoria at $0^{o}20'N.32^{o}36'E.$, at 1,312 meters (4,304 feet). It has the highest number of thunderstorm days of any place listed in the World Distribution of Thunderstorm Days.[191] The record for Kampala is based on a period of 10 years, but the particular years are not given. Because diurnal variations of air temperature are very small over Lake Victoria and large over the surrounding area, land and lake breezes develop and conditions become favorable for thunderstorms. "...Land-breeze convergence over the Lake during the night releases the latent instability of the moist lower layers of air over the Lake which participate in the land breeze circulation, resulting in the development of cumulonimbus clouds and thunderstorms over the Lake on most nights of the year...."[192] When these storms are close enough for thunder to be heard at Kampala, they are counted as thunderstorms there, even though they do not actually reach the town.[193] In addition to these night storms, others develop over land at certain times of the year from afternoon convection at the lake breeze front.[194] Thus, the Kampala area is subject to frequent thunderstorm activity, and nearby

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[190] W.H. Portig and J.R. Gerhardt, Research in Tropical Meteorology, Second Interim Technical Report, Austin, Texas, Univ. of Texas, Electrical Engineering Research Laboratory (Sponsored by U.S. Army Research and Development Laboratory, Fort Monmouth, New Jersey), 1962.

[191] World Meteorological Organization, World Distribution of Thunderstorm Days, Geneva, Switzerland (OMM, No. 21), 1953.

[192] F.E. Lumb, "Topographic Influences on Thunderstorm Activity Near Lake Victoria", Weather, Vol. 25, No. 9, pp. 404-10, 1970.

[193] W.H. Portig, Research Meteorologist, U.S. Army Tropic Test Center, Fort Clayton, Canal Zone, correspondence dated 23 Nov 70.

[194] F.E. Lumb, op. cit.

stations such as Entebbe and Kisumu also average very high numbers of thunderstorm days per year.[195]

Bogor, Indonesia, averaged
322 thunderstorm days per year
1916 to 1920

Bogor, formerly Buitenzorg, is located on the island of Java at $6^{\circ}30'$S. $106^{\circ}48'$E. The mean annual number of thunderstorm days recorded there changed from 151 in the years 1841 through 1857 to 322 from 1916 through 1919; it ranged from 4 to 41 for the years 1953 through 1962.[196] These differences might reflect changes in the criteria for recording thunderstorms. For instance, "...during a certain period...." Bogor recorded lightning seen in addition to thunder heard and thunderstorm at the station.[197] Also, the interpretation of 322 in the Bogor record is doubted by W. H. Portig and others who consider that it represents the "...mean number of occurring thunderstorms and not the mean number of days on which thunder was heard...."[198] According to Portig, the "...absolute occurring maximum...." is indicated by statistical curves to be "...approximately 250 or 260 thunderstorm days annually, although such a location has not as yet been found...."[199]

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[195] Ibid.

[196] V.I. Arabadzhi, "Klimat i grozy" [Climate and Thunderstorms], Priroda, No. 2, pp. 65-66, Feb 66 (Translated by E.R. Hope as Canada. Defence Research Board, Translation T456R, Apr 66).

[197] W.H. Portig, op. cit.

[198] W.H. Portig, "Thunderstorm Frequency and Amount of Precipitation in the Tropics, Especially in the African and Indian Monsoon Regions", Archiv für Meteorol, Geophysik und Bioklimatol, Ser. B, Vol. 13, No. 1, pp. 21-35, 1963.

[199] Ibid.

b. Air Pressure. The pressure value for a given unit area of surface very nearly represents the actual weight of a vertical column of air of the same unit area extending upward from that surface to the top of the atmosphere. At sea level this column of air averages about 99.2 kilopascals (29.92 inches of mercury) per square inch of exposed surface, but the weight varies with latitude and with changes in daily weather. It falls with altitude from an average of 106 kilopascals (31.3 inches) in the earth's deepest depression, 396 meters (1,300 feet) below sea level, to less than half that amount, about 50 kilopascals or 14.9 inches at 5,486 meters (18,000 feet). At the top of the world's highest mountain, 8,848-meter (29,028-foot) Mount Everest, it would be about 30.5 kilopascals (9 inches).

Air pressure is usually measured by mercurial or aneroid barometers. The former balances pressure of the atmosphere against the weight of a column of mercury. The aneroid, or elastic, type contains a hollow metal chamber, partly emptied of air and sealed, that expands and contracts as the pressure changes. Mercurial barometers are generally more accurate, but the aneroids are smaller and more portable. Because mercury is affected by temperature and gravity, adjustments must be made in the readings of mercurial barometers to allow for these factors. Also, in order to standardize readings of any kind of barometer when made at different times and places, adjustments are required to compensate for errors in the individual instrument used (index error) and for differences in altitude. For the altitude adjustment, the station pressure readings are usually equated to sea level pressure and the resulting values (which are lower for elevations below sea level and higher for elevations above sea level) are recorded. There are possible sources of error peculiar to each type of barometer, as well as errors that could occur from making the various types of adjustments. For example, different values can be obtained when different methods are used for equating station pressures to their sea level equivalents.

(1) High Pressure. The highest observed pressures (not equated to sea level) occur at the lowest elevations, i.e. in depressions below sea level such as Death Valley, California, where the lowest point is -85 meters (-280 feet); the Qattara depression in northwestern Egypt, with a minimum elevation

of -133 meters (-436 feet); and the shores of the Dead Sea between Israel and Jordan, at -392 meters (-1,286 feet). In the Dead Sea area, a pressure of 108.06 kilopascals (31.91 inches) was reported at Sedom (the biblical Sodom) on 21 February 1961.[200] Another depression, the Turfan in central Asia, at approximately 45°N.90°E., is thought to have pressures similar to or even higher than those of the Dead Sea area.[201] At or near sea level, high pressures occur along Arctic coasts. A value of 106.43 kilopascals (31.43 inches) was recorded at Barrow, Alaska, on 3 January 1970.[202] This is the record high pressure for the United States.

World's highest sea level air pressure
108.38 kilopascals (32.01 inches)
Agata, U.S.S.R., 31 December 1968

The highest recorded pressures (equated to sea level) occur in Siberia during winter. Agata is located in this area at 66°53'N.93°28'E., elevation 261 meters (855 feet). The high pressure record there was the culmination of an intense anticyclone which originated in East Siberia on 22 December 1968 and continued until 2 January 1969, when it declined somewhat as it moved south and west into European Russia.[203] On 31 December, seven stations in north-central Siberia had air pressures above 107 kilopascals (31.565 inches). The weather was clear and calm with temperatures between -40° and -50°C (-40 and -58°F). At 1200 hours GMT, the pressure in the center of the

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[200] A. Court, "Improbable Pressure Extreme: 1070 mb", Amer Meteorol Soc Bull, Vol. 50, No. 4, pp. 248-50, Apr 69.

[201] A. Loewe, "More on 'Improbable Pressure Extreme: 1070 mb'", Amer Meteorol Soc Bull, Vol. 50, No. 10, pp. 804-806, Oct 69.

[202] R.J. Schmidli, op. cit.

[203] B.D. Giles, "Extremely High Atmospheric Pressures", Weather, Vol. 25, No. 1, pp. 19-24, 1970.

anticyclone "reached 1083.3 mb" according to M.V. Burkova and V.A. Dzhordzhio[204] who analyzed the meteorological and environmental conditions contributing to the extreme high pressure. This record has been authenticated. However, a previous world record "of 1079 mb at Barnaul", Siberia, was found to be "exaggerated".[205] The 107.51 kilopascals (31.75 inches) recorded at Irkutsk, Siberia, in 1893 might remain the second highest world record.

(2) Low Pressure. The lowest pressures occur at the highest altitudes, e.g. in the Himalayas of Asia, the Andes in South America, and the Rockies in western North America. Beginning at about 1,219 meters (4,000 feet), the average station pressures are lower than the most extreme low pressures that occur at sea level. At the approximate upper limit of weather stations, 4572 meters (15,000 feet), standard pressure is 57.23 kilopascals (16.90 inches) and the extreme lowest is estimated at about 49.98 kilopascals (14.76 inches).[206] At sea level the lowest pressures and most rapid falls in pressure occur during tornadoes. "...Accurate pressure measurements by a recorder directly in the center of a tornado have never been made...."[207], but various estimates are available. Among these are Court and Salmela's "...a reduction of no more than one fourth of the pre-existing pressure...." which could occur "...within 15 seconds..."[208]. Fujita's estimate calls for a drop of 1.5 pounds per square inch (10 kilopascals or 3 inches) and a time change of 0.5 psi (3.4 kilopascals or 1 inch) per second in pressure of

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[204] M.V. Burkova and V.A. Dzhordzhio, "O mirovom rekorde davleniya na urovne morya" [World record of sea level pressure], Tashkent. Sredneaziatskiy Regional'nyy Nauchno Issledovatelskiy Gidrometeorologicheskiy Institut, Trudy, Vol. 86, No. 5, pp. 166-74, 1973.

[205] Ibid.

[206] A. Court and H.A. Salmela, "Improbable Weather Extremes and Measurement Needs", Amer Meteorol Soc Bull, Vol. 44, No. 9, pp. 571-75, Sep 63.

[207] D.M. Ludlum, op. cit.

[208] A. Court, and H.A. Salmela, op. cit.

in pressure of tornadoes with 200-mile per hour winds.[209] Because of the sudden drop that occurs, differences between the pressure outside a building and the higher pressure still remaining inside can cause the building to explode. The force of the wind can contribute to this effect.

World's lowest air pressure at sea level
(excluding tornadoes)
87.00 kilopascals (25.69 inches)
estimated by dropsonde in eye of Typhoon Tip at
16°44'N.137°46'E., 12 October 1979

This record, which occurred 520 miles northwest of Guam, was based on a dropsonde observation made from a reconnaissance aircraft of the U.S. Air Weather Service. As the plane approached the center of the eye of the storm, "flight level pressures fell rapidly until the absolute altimeter read 6,590 feet and the pressure altimeter, 10,040 feet! These readings produced a 700 mb height of only 1,900 meters"[210] and a new world record. Although a major source of error in this type of measurement would be in the aircraft altimetry, calibration checks are a routine part of each flight on reconnaissance aircraft.

The low pressure record of Typhoon Ida, which was included on previous maps of world weather extremes, was obtained by the same method, as was the record of Typhoon June, which surpassed Ida's on 19 November 1975. The lowest pressure during Ida was 87.7 kilopascals (25.90 inches) and during June, 87.6 kilopascals (25.87 inches).[211] June was distinguished by the abruptness of the fall in pressure. Most of it, 5.2 kilopascals (1.5

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[209] T.T. Fujita, Estimate of Maximum Wind Speeds of Tornadoes in Three Northwestern States, Chicago Univ., Ill. Dept. of the Geophysical Sciences, Research Paper 92, NOAA-71060308, Dec 70.

[210] "World Record Low, from AWS Observer, March 1980", National Weather Assoc Newsletter, No. 80-3, p. 3, Apr 80.

[211] R.J. Schmidli, op. cit.

inches), fell in 11 hours.[212] Pressures remained below 90 kilopascals (26.5 inches) over a very long period (36 hours).[213]

The lowest pressure that has actually been measured at sea level was 88.673 kilopascals (26.185 inches) on the Sapoerea at 740 kilometers (460 miles) east of Luzon, Philippine Islands, on 18 August 1927.[214] All of the records of extreme low pressure during tropical cyclones mentioned above have occurred in the Philippine Sea area of the western North Pacific Ocean.[215] This area also has a very high frequency of intense tropical cyclones equal to or greater than 34 knots (63 kilometers per hour or 39 miles per hour).[216] According to information from the U.S. Navy's Mariners Worldwide Climatic Guide to Tropical Storms at Sea by Crutcher and Quayle, Luzon in the Philippine Islands experiences an average of five of these storms a year. Manila, most probably, holds the frequency record among the world's large urban areas.

c. Solar Radiation. Measurements of the flux of solar radiation penetrating to the lower layers of the atmosphere can be subdivided into several main classes. Values considered here are for global solar radiation received on a horizontal surface. "...This includes both radiation received direct from the solid angle of the sun's disc and also radiation that has

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[212] C.R. Holliday, "Typhoon 'June' Most Intense of Record", Monthly Weather Rev, Vol. 104, No. 9, pp. 1188-90, Sep 76.

[213] M. Rodewald, "Neuer Tiefdruck-Rekord auf der Erde" [New Low Pressure Record on the Earth], Der Seewart, Hamburg, Vol. 38, No. 2, pp. 87-88, Apr 77.

[214] R.J. Schmidli, Weather Extremes, Salt Lake City, Utah, U.S. National Oceanic and Atmospheric Administration, National Weather Service (NOAA Tech Memo WR-28 and Western Region Tech Memo No. 28), Nov 71.

[215] M. Rodewald, "Die tiefsten Druckrichter tropischer Zyklonen" [Lowest Pressure Funnels of Tropical Cyclones], Der Seewart, Hamburg, Vol. 38, No. 1, pp. 1-6, Feb 77.

[216] Ibid.

been scattered or diffusely reflected in traversing the atmosphere...."[217] Such measurements are usually made with pyranometers, and as in all radiation measurements, considerable care and attention to detail is required to ensure accuracy. Several points to be evaluated in estimating accuracy of radiation measurements are listed in the WMO Guide.[218]

South Pole has
463 W/m^2 (955 langleys)
average daily insolation in December

Solar radiation values vary with time and place according to factors such as latitude and atmospheric clarity. The world's highest daily amounts of solar radiation are received on the Antarctic Plateau during summer, when there are 24 hours of continuous daylight.[219] The North Polar area also has continuous daylight during its summer, but at that time of the year the earth is about 3 million miles further from the sun. Consequently, about 7 percent less solar radiation impinges on the top of the Arctic's atmosphere during midsummer.[220] The South Pole record was obtained by averaging daily values of hemispheric global solar radiation, which were available from Amundsen-Scott Station at 90°S, elevation 2,800 meters (9,186 feet) for the Decembers of 1958 through 1965.[221] The resultant value was 954.6 langleys, equivalent to 463 W/m^2 or 954.6 g-cal cm^{-2} day $^{-1}$. However, the average daily insolation could be even greater at other stations on the

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[217] World Meteorological Organization, Guide to Meteorological Instrument and Observing Practices, op. cit.

[218] Ibid.

[219] K.J. Hanson, "Some Aspects of the Thermal Energy Exchange on the South Polar Snow Field and Arctic Ice Pack", Monthly Weather Rev, Vol. 89, No. 5, pp. 173-77, May 61.

[220] Ibid.

[221] U.S. Environmental Science Services Administration, Environmental Data Service, Climatological Data for Antarctic Stations, Nos. 1 and 9, Washington, D.C., GPO, 1962 and 1968.

Antarctic Plateau.[222] In contrast to these high daily values, the polar areas do not have high annual and hourly solar radiation values because of the continuous darkness during winter months and the increased obliqueness of the sun's angle at higher latitudes.

The highest annual values of solar radiation are observed in desert areas of northeastern Africa,[223] where there is very little cloud cover and the sun's rays are never very oblique and are near vertical at the time of the summer solstice. High hourly values of solar radiation can be expected at relatively low latitudes during the hours of the day and times of the year when the sun's angle is most nearly vertical, when cloud cover is absent, and when the air is as clear as possible from dust and other impurities. Other things being equal, high hourly values would tend to occur at the higher elevations.

Some very high hourly values have been reported from western Africa south of the equator. Malange, Angola, had a value of 1,314 W/m^2 (113 langleys) in one hour on 7 November 1961[224] and Windhoek, Southwest Africa, had 1,303 W/m^2 (112 langleys) in 1 hour on 20 December 1956.[225] Malange is located at $9^{\circ}33'$S.$16^{\circ}22'$E., altitude 1,131 meters (3,710 feet) and Windhoek is at $22^{\circ}34'$S.$17^{\circ}16'$E., altitude 1,728 meters (5,640 feet).

d. Wind Speed. Of all the elements, wind is most variable. To compare wind speeds reported from various places and times, information should be known about the height and exposure of the measuring instrument (anemometer),

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[222] Personal communication, M. Kuhn, University of Innsbruck, Innsbruck, Austria.

[223] M.I. Budyko, The Heat Balance of the Earth's Surface, N.A. Stepanova, Transl., U.S. Department of Commerce, Washington, D.C., 1958.

[224] Quart Radiation Bull, Union of South Africa, Vol. 8, No. 2, p. 160, 1961.

[225] Quart Radiation Bull, Union of South Africa, Vol. 3, No. 1/2, p. 47, 1957.

the type of instrument and record, and the time interval covered by the measurement. Wind speed is usually measured by either rotating or pressure anemometers. In the former type, wind passage is measured by the rate of motion imparted to a freely rotating mechanism, and a timing mechanism is usually combined with the anemometer to indicate the rate of passage. Pressure anemometers measure the instantaneous speeds (actually averages for about 1 second) by means of pressure effects, i.e. force applied to a surface or surfaces. The time intervals of wind observations differ between countries and even between stations. In the U.S. the values tabulated, as of 1981, include "peak wind, the greatest 5-second average wind speed during the previous hour that exceeded 35 knots or 17 m/s"[226] and "fastest mile, the fastest wind speed in miles per hour of any wind over the 24-hour observation day".[227] Converting to units used in this publication, peak wind would exceed 64.9 kilometers per hour or 40.3 miles per hour. In addition, wind gusts (sudden brief increases in the speed of the wind)[228] and gust spread between peak and lull are also included. For many years, prior to the use of more sophisticated instruments, the standard observation was the number of miles of wind passing the anemometer in five minutes multiplied by 12 to obtain the miles per hour.[229]

Winds are strongest at the times and places of maximum temperature and pressure gradients. They increase with altitude and during thunderstorms, hurricanes, and tornadoes. A tornado is defined as "a phenomenon consisting of an often violent whirlwind, revealed by the presence

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[226] U.S. National Oceanic and Atmospheric Administration, Federal Coordinator for Meteorological Services and Supporting Research, Federal Standard Definitions for Meteorological Services and Supporting Research, FCM-S1-1981, Washington, D.C., Nov 81.

[227] Ibid.

[228] R.F. Huschke, ed., Glossary of Meteorology, Boston, Mass, Amer Meteorol Soc, 1959.

[229] N. Sissenwine and R.V. Cormier, Synopsis of Background Material for MIL-STD-210B, Climatic Extremes for Military Equipment, U.S. Air Force Cambridge Research Laboratories AFCRL-TR-74-0052 and Air Force Surveys in Geophysics, No. 280, Bedford, Mass., 24 Jan 74.

of a cloud column or inverted cloud cone (funnel cloud), protruding from the base of a cumulonimbus, and of a 'bush' composed of water droplets raised from the surface of the sea or of dust, sand or litter raised from the ground."[230] It is believed that the most extreme windspeeds that occur on the earth are those found in the suction vortices that orbit around the centers of tornadoes. However, according to T.T. Fujita, as of 1981 it was not yet possible to measure these speeds accurately.[231] Measuring instruments would be unable to withstand the impact. Ways of estimating extreme wind speeds by various means such as photogrammetry, engineering, minimum pressure, funnel shape, etc., have been devised. An example is Fujita's scale of windspeed/damage relationships that ranges from "light" damage at 64-116 kilometers per hour (40-72 miles per hour) to "incredible" damage at 420-512 kilometers per hour (261-318 miles per hour) and "inconceivable" damage above these values.[232] Since some tornadoes have caused "incredible" damage, windspeeds of at least 420 kilometers per hour (261 miles per hour) would have occurred. Worldwide, tornadoes occur most often in the United States, where they are most prevalent in states like Kansas, Oklahoma, and Texas, which are near the eastern foot of the Rocky Mountains. These areas also have a high incidence of severe hailstorms.

World's highest surface wind (excluding tornadoes)
372 kilometers per hour (231 miles per hour), peak gust
303 kilometers per hour (188 miles per hour), 5-minute wind speed
12 April 1934
Mount Washington, New Hampshire

Winds are stronger at the summit of this 1,916-meter (6,288-foot) mountain, at 44°16'N.71°18'W., than they are at the same elevation in the

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[230] World Meteorological Organization, International Cloud Atlas, Vol. 1, Manual on the Observation of Clouds and Other Meteors (Partly Annex 1 to WMO Technical Regulations), op. cit.

[231] T.T. Fujita, "Tornadoes and Downbursts in the Context of Generalized Planetary Scales", J Atmospheric Sciences, Vol. 38, No. 8, pp. 1511-34, Aug 81.

[232] Ibid.

free air some distance away. "...This is probably due to 'uplift' over the slope or to the Bernoulli effect introduced by the surrounding mountains. Windspeeds of 161 kilometers per hour (100 miles per hour) are not uncommon...."[233] The speed of the peak gust was measured by a heated rotation anemometer, but in such strong winds no apparatus can record the airflow except approximately, and actual velocity may be in error by 16 to 64 kilometers per hour (10 to 40 miles per hour).[234,235] The 372-kilometer-per-hour (231-mile-per-hour) value is documented in the official records.[236] A value of 225 miles per hour, after anemometer calibration, is given in some sources[237] and was cited in earlier editions of the world weather extremes map. Direction of the wind during the gust was from the southeast, the direction from which the most severe storms in the Mount Washington area usually come. Its force, due to the reduced air density on the mountain top, was equal to that of about a 180-mile-per-hour wind at sea level.[238] The 24-hour period during which the gust was recorded had a mean wind speed of 206 kilometers per hour (128 miles per hour) and a speed of 278 kilometers per hour (173 miles per hour) during the fastest hour.[239]

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[233] U.S. National Oceanic and Atmospheric Administration, National Climatic Data Center, Local Climatological Data; annual summary with comparative data, 1982. Mount Washington Observatory, Gorham, New Hampshire, Asheville, N.C., 1983.

[234] C.F. Brooks, "The Worst Weather in the World", Appalachia, pp. 194-202, Dec 40.

[235] "Note on the Precipitation, Snowfall and Wind Records", Mount Washington Observatory News Bull, No. 22, pp. 23-24, Jun 53.

[236] U.S. National Oceanic and Atmospheric Administration, National Climatic Data Center, Local Climatological Data; annual summary with comparative data, 1982 Mount Washington Observatory, Gorham, New Hampshire, op. cit.

[237] A. Court, "Wind Extremes as Design Factors", J Franklin Inst, Vol. 256, pp. 39-56, Jul 53.

[238] Ibid.

[239] S. Pagliuca, et. al., "The Great Wind of April 11-12, 1934, on Mt. Washington, N.H., and Its Measurement", Monthly Weather Rev, Vol. 62, pp. 186-89, Jun 34.

Next to the world record peak gust, the second highest gust that has occurred on Mount Washington is apparently the 304 kilometers per hour (189 miles per hour) estimated during the hurricane of 21 September 1938.[240] The annual mean wind speed recorded on Mt. Washington, which varies with the period of observation, was 56 kilometers per hour (35.1 miles per hour) for the 48-year period through 1982.[241]

Thule, Greenland, had a peak gust of
333 kilometers per hour (207 miles per hour)
8 March 1972

This peak wind speed of 180 knots was recorded at 9:55 p.m. at an off-base survival shelter at 76°31'20''N.68°19'00''W., elevation 302 meters (990 feet).[242] It was observed by two site dispatchers on an anemometer capable of registering winds of up to 444 kilometers per hour (276 miles per hour). It occurred at a considerably lower elevation than the peak gust on Mount Washington and consequently could have exceeded it in force. The gust was observed during a severe Arctic storm in which the site experienced winds of 235 kilometers per hour (146 miles per hour) or greater for 4 hours. Similar, though somewhat lesser, speeds were observed throughout the area. The U.S. Air Base at Thule had a speed of 177 kilometers per hour (110 miles per hour). High winds are common in this northwest Greenland area due to intense winter storms and local topographic conditions. Winds blowing down from the dome-shaped Greenland icecap are accelerated by gravity and by compression and funneling as a result of the local orientation of mountains and valleys.

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[240] C.F. Brooks, "The Worst Weather in the World", op. cit.

[241] U. S. National Oceanic and Atmospheric Administration, National Climatic Data Center, Local Climatological Data; annual summary with comparative data, 1982, Mount Washington Observatory, Gorham, New Hampshire, op. cit.

[242] J.R. Stansfield, "The Severe Arctic Storm of 8-9 March 1972 at Thule Air Force Base, Greenland", Weatherwise, Vol. 25, No. 5, pp. 228-33, 1972.

Miyakojima Island, Ryukyu Islands
had a peak gust of
306 kilometers per hour (190 miles per hour)
5 September 1966

Hurricanes, called typhoons in the Pacific area, are defined on the basis of their wind speed as tropical cyclones with winds of 65 knots (119 kilometers per hour, 74 miles per hour) or higher or as tropical cyclones with wind Beaufort force equal to 12 or more.[243] Hurricane winds can sometimes be measured, but in the most severe storms the anemometers usually fail before the peak values are reached. As with tornadoes, various methods are used for estimating the hurricane wind speeds, and a scale (Saffir/Simpson) has been developed for rating the severity of the storms.[244] Those in the highest category of the scale have air pressure less than 92 kilopascals (27.17 inches) and winds over 249 kilometers per hour (155 miles per hour), and they cause "catastrophic" damage. Because pressure gradients "have a reasonably close relationship to the wind speeds since the two quantities are related physically"[245], they are often used to estimate hurricane winds. Surface winds during Typhoon Tip, which had the world's lowest sea-level air pressure, were estimated by the Joint Typhoon Warning Center of the U.S. Navy and U.S. Air Force to be 160 knots (296.5 kilometers per hour or 184 miles per hour) with gusts to 195 knots (361 kilometers per hour or 225 miles per hour).[246] Maximum winds in the two United States hurricanes with lowest pressures, at Matecumbe Key, Florida, in 1935 and on the coast of Louisiana and Mississippi in 1969 (Camille) have been estimated at about 200 miles per

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[243] R.E. Huschke, ed., op. cit.

[244] P.J. Hebert and G. Taylor, "Hurricanes", Weatherwise, Vol. 32, No. 3, pp. 100-107, Jun 79.

[245] R.C. Gentry, "Extreme Winds in Hurricanes and Possibility of Modifying Them", In: Wind and Seismic Effects; Proceedings of the Sixth Joint Panel Conference of the U. S.-Japan Cooperative Program in Natural Resources, May 15-17, 1974, Gaithersburg, MD., H. S. Lew, Editor, U.S. National Bureau of Standards, Special Publication No. 444, issued April 1976, pp. I-21-I-33.

[246] "World Record Low, from AWS Observer, March 1980", op. cit.

hour (322 kilometers per hour).[247]

A peak gust of 85.3 meters per second (306 kilometers per hour or 190 miles per hour) and a maximum wind of 60.8 meters per second (219 kilometers per hour or 136 miles per hour) were observed at the weather station on Miyakojima Island, Ryukyu Islands, and officially reported by the Ryukyu Meteorological Agency.[248] They occurred during a typhoon whose maximum wind zone passed over the small flat island located in the Western North Pacific Ocean at about 24°47'N.17°E. The Western North Pacific Ocean has the world's largest, most intense, and most frequent tropical cyclones. Each year about 18 typhoons occur there, according to the U.S. Navy's Mariners Worldwide Climatic Guide to Tropical Storms at Sea, by Crutcher and Quayle; and each year, one or two of the storms equals the one at Miyakojima in severity.[249] The United States averages about two hurricanes per year; and Florida is the state where they occur most often.[250]

Port Martin, Antarctica, had mean wind speed for 24 hours of
174 kilometers per hour (108 miles per hour)
21-22 March 1951 and
mean wind speed for 1 month of
105 kilometers per hour (65 miles per hour)
March 1951

These wind speeds were recorded at a station maintained by the Expéditions Polaires Françaises at 66°49'S.141°24'E. on the coast of Adélie

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[247] R.C. Gentry, op. cit.

[248] Y. Mitsuta and S. Yoshizumi, "Characteristics of the Second Miyakojima Typhoon", Kyoto, Japan, Univ, Disaster Prevention Research Bulletin, Vol. 18, pt. 1, No. 131, pp. 15-34, 1968.

[249] Ibid.

[250] P.J. Hebert and G. Taylor, op. cit.

Land from February 1950 to January 1952.[251] The wind-measuring installations did not fully comply with international standards, being somewhat sheltered by snowdrifts, or the values would have been slightly higher. Winds of hurricane force equal to or greater than 119 kilometers per hour (74 miles per hour) were recorded at the station on 10 consecutive days in March 1951 and on 122 days during calendar year 1951. The hurricane force winds are extremely steady both in their direction, south-southeast, and in their strength, which varies very little and appears lacking in normal gustiness. However, they can drop within a minute from full hurricane strength to near-calm and just as suddenly return. Extreme winds were also reported by Mawson's expeditions at nearby Cape Denison, 67°1'S.142°41'E. in 1912 and 1913.[252] Various explanations of the causes of strong winds in this part of Antarctica have been advanced,[253] but as yet the reasons for them are not definitely established.[254]

e. Dew Point (Humidity). Dew point is "...the temperature to which a given parcel of air must be cooled at constant pressure and constant watervapor content in order for saturation to occur...."[255] This is the temperature at which the vapor returns to liquid water. It is measured by dew-point hygrometers in which a mirror or other element is cooled to the saturation point. High dew points indicate high humidity, and low dew points indicate low humidity. The high values cannot be higher than the temperature of the body of water from which the vapor originates. They occur in proximity to water bodies with high surface temperatures, such as parts of the Gulf of California, the Red Sea, the Persian Gulf, and possibly in some tropical swamplands. One of the highest dew points ever recorded is 34°C

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[251] F. Loewe, "The Land of Storm", Weather, Vol. 27, No. 3, pp. 110-21, 1972.

[252] Ibid.

[253] K.B. Mather and G.S. Miller, "The Problem of the Katabatic Winds on the Coast of Terre Adélie", Polar Record, Vol. 13, pp. 425-32, 1967.

[254] F. Loewe, op. cit.

[255] R.E. Huschke, ed., op. cit.

(93.2°F) at Sharjah, Saudi Arabia, on the western shore of the Persian Gulf.[256] It occurred at 1600 LST on a day in July during one of the years between 1948 and 1953.

Assab, Ethiopia, has
29°C (84°F)
average afternoon dew point in June

The dew point value for Assab was taken from a footnote in a report by A. V. Dodd. "...Recently available data furnished by the National Weather Records Center indicate that very high dew points occur also in the Red Sea littoral. Assab and nearby Ras Andahglie on the Red Sea coast of Eritrea (Ethiopia) had average afternoon dew points higher than 84°F..."[257] This value was for the most extreme month which, according to the author of the report, is June.

f. Fog.

U.S. West Coast foggiest place
2,552 hours per year average frequency
Cape Disappointment, Washington

U.S. East Coast foggiest place
1,580 hours per year average frequency
Moose Peak Lighthouse, Mistake Island, Maine

Fog is a "suspension of minute water droplets which are based on the earth's surface and extend vertically to at least 20 feet (6 m) and reduces

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[256] H. Salmela and D.D. Grantham, Diurnal Cycles of High Absolute Humidity at the Earth's Surface, AFCRL-72-0587, ERP 416, U.S. Air Force Cambridge Research Laboratories, Bedford, Mass., 1972.

[257] A.V. Dodd, Areal and Temporal Occurrence of High Dew Points and Associated Temperatures, Tech Rpt ES-49, U.S. Army Natick Laboratories, Natick Mass., Aug 69.

horizontal and vertical visibility".[258] It can occur, if there are sufficient condensation nuclei present, whenever the air is cooled to its dew point or the dew point is raised by the addition of moisture to the air. Fog occurs most often on mountains, where the surface of the earth is high enough to be in the clouds, and on coasts, where land and water temperatures differ and moisture is present. Mountain stations with very frequent occurrences of fog are Mt. Washington, New Hampshire, averaging 308 days a year on which there is some fog and Stampede Pass at 1206 meters (3958 feet) in Washington, which averages 252 days a year.[259] The records for Cape Disappointment, at the mouth of the Columbia River in Washington, and Moose Peak Lighthouse, off the northern coast of Maine, are based on fog signal operation and on low visibility operation of radio beacons at light stations, lightships, and other Coast Guard units during a period of 10 years or longer. They were obtained from M. A. Arkin, then of the U.S. Environmental Data Service, who also contributed a record for Willapa on the coast of Washington. At this place, the average was 3,863 hours of fog per year for a 4-year period; and for one of those years there was a total of 7,613 hours of fog.

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[258] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Federal Coordinator for Meteorological Services and Supporting Research, Federal Standard Definitions for Meteorological Services and Supporting Research, *op. cit.*

[259] D.M. Ludlum, *op. cit.*

III. CONCLUSIONS

From the foregoing examples and discussions of weather extremes and their records, several points seem to stand out:

a. For each meteorological and climatological element there are certain conditions or combinations of conditions that tend to favor the occurrence of extreme values. These conditions are most likely to be present in particular geographical areas or during particular seasons of the year. Also, there are upper and lower limits of the extreme values that could possibly occur. The records shown on the two maps considered in this publication appear to be within the limits of possibility and to have occurred in places and at times in which the necessary conditions could be expected to happen. However, occurrences of equal or greater extremity could have happened at other places in the same areas or at other times in the same places without being recorded or without being publicized. There is no routine exchange of such information between different countries.

b. For each meteorological and climatological element, there are factors of site, instrumentation, and observational procedure that can affect the measured values. To ensure uniformity of measurements, certain standardized equipment and procedures are recommended by the World Meteorological Organization. However, standardized equipment can malfunction, and errors can be made in observation and recording, even under standard procedures. Further, improvements in the reliability of measurements continue to be made as knowledge of both technology and the physical environment increases. Some of the earlier records might have different values if measured with the newest instruments and procedures; even now, extremes are sometimes not measured exactly, or at all, because they exceed the scale of standard meteorological instruments or their rate of response.[260] For these reasons, it is not to be assumed that any one of the values shown on the two maps considered in this publication is correct to the tenth of a decimal place. However, those for which a claim for record

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[260] A. Court and H.A. Salmela, op. cit.

extreme is made were obtained under conditions that were acceptable to the responsible weather service organizations.

c. Considerable research remains to be done on both the general subject of extreme weather and climate and on the records of individual extreme occurrences. There is more to be learned about the causes of extreme conditions as well as their absolute limits, frequencies, and distributions in time and place. Further search would yield additional records of extremes and of categories of extremes which are not included on the present maps.

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